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POLLUTION IMPLICATIONS OF ANIMAL WASTES -- A FORWARD ORIENTED REVIEW

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27 Abstract

The purpose of this review was to present a forward oriented state-of-the-art of pollutional implications which must be faced with the ever increasing trend toward confinement feeding large numbers of livestock. The manure wastes from all varieties of livestock under feed in the United States are characterized and related both to human population equivalents and beef cattle equivalents. The potential environmental hazards which may result from improper handling, storage, and disposal of these wastes were discussed. The effectiveness and economics of various conventional wastes treatment and disposal methods as related to confinement feeding wastes were evaluated.

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POLLUTION IMPLICATIONS OF ANIMAL WASTES-- A FORWARD ORIENTED REVIEW

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FOREWORD

Reflecting the increasing concern of the people of the United States, the Congress has, since 1948, provided legislation to combat water pollution. This concern eventually culminated in the Water Quality Act of 1965 which established the Federal Water Pollution Control Administration to carry out the Federal program for renovation and protection of our Nation's water resources. Pollution from animal wastes is a relatively new but rapidly expanding threat to these resources and requires an immediate response.

Although the total volume of animal waste produced in the United States is about ten times that of the human population, little concern has resulted until the last decade. Previously, most animals were produced in unconfined areas where wastes could be assimilated by the environment with little or no detrimental effects. The recent logarithmic increase in concentrated feeding operations and the ever greater proximity of these operations to metropolitan areas has overtaxed the natural assimilative capacity of producing areas and demanded control of resulting effluents.

Even now, the implications of the animal waste problem are not fully realized by the general public, livestock operators, or by many scientists concerned with water pollution control. Waste management technology continues to lag behind the rapid growth of the livestock industry, and the gap widens. The reversal of this trend and prevention of uncontrolled pollution of this Nation's most valuable natural resource demand, as the first step a greater awareness of the problem.

The following report discusses the magnitude of the problem, presents presently applicable technology, and outlines areas where additional information is needed. The immediate goal is to concentrate problems and possible solutions of animal waste management into a document of benefit to the livestock producer, researchers, and other individuals or agencies concerned with water pollution control. The ultimate goal is the restoration and maintenance of the Nation's water at a quality commensurate with the will of the people and the technology of which we are capable.

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Research Sanitary Engineer
Robert S. Kerr Water Research Center

At the time this paper was prepared and until February 1, 1968, Dr. Loehr was Professor of Civil Engineering at the University of Kansas, Lawrence, Kansas.

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SUMMARY RECOMMENDATIONS

The specific aim of this study was to develop a forward oriented review of the problem of animal waste control and abatement. The review attempted to summarize the present body of knowledge, indicate major problem areas, suggest feasible research and development applicable to the problem, and identify legislative and technical areas needing further emphasis.

Hopefully, this study will assist in the preparation of directions and program plans to assure that the pollution control activities of the nation stay ahead of the problems in this area rather than attempting to solve them after gross pollution and damage have occurred.

The recommendations resulting from this study are:

1. That objectives be set with regard to acceptable degrees of treatment and disposal to control problems that will result from indiscriminate discard of animal wastes into the environment. Adequate education, research, development, and training concerning these problems should be given high priority.

2. That future research and educational activities dealing with animal wastes develop and emphasize the interrelationships of animal production operations and waste management operations, such as waste handling, treatment, and disposal operations, to eliminate pollution from animal production facilities.

3. That future training activities be separated from research activities. Training activities should not be the source of the major research in animal waste control and abatement.

4. That educational and training activities aimed at the control and abatement of animal waste pollution include: (a) formal training and education to produce professional people capable of solving the problem, (b) education of the general public and the agricultural community to the magnitude and costs of the problem, (c) opportunities such as senior fellowships at qualified educational institutions and in governmental organizations to broaden the background, training, and experience of professionals competent in only one aspect of animal waste control and abatement, and (d) workshops at all levels to disseminate information concerning the problem and proper techniques for its solution.

5. That all projects conducting research on animal waste control and abatement collect data on the waste characteristics. Information concerning housing and management practices, rations fed, and waste handling and collection practices used in the project also should be reported.

6. That a detailed study be initiated to delineate the proper analytical techniques to be used for animal wastes. Proper techniques for accurate determination of waste characteristics, performance of treatment facilities, and quality of resultant effluents are needed.

7. That coordinated, interdisciplinary research activities be initiated to: (a) investigate all possible animal waste treatment processes, (b) develop new processes for waste handling, treatment, and disposal, (c) provide information on processes for

both solid, liquid handling and treatment of the wastes, (d) determine how these processes interact with animal production operations, (e) provide detailed data on the quality of the solid, liquid, and gaseous materials, if any, that result from these processes, (f) itemize the construction, maintenance operations, and personnel costs associated with the processes, (g) investigate better control of the wastes at the source, i.e., the animal, and (h) delineate possible treatment systems that may be used to meet the control and abatement objectives of a region and/or the nation.

8. That research be conducted on the process effluents from animal wastes to: (a) determine possible detrimental concentrations of materials such as nitrogen, phosphorus, chlorides, color, and others that could prevent the effluents from being discharged or reused, (b) develop suitable tertiary processes and systems to allow the effluents to be discharged or reused, and (c) determine the possible effect of secondary and tertiary effluents on receiving surface and ground waters and in possible reuse systems.

9. That considerable emphasis be given to the assessment of feasible ultimate disposal techniques for untreated solids and liquids as well as for the residues from waste treatment processes. These techniques should be integrated with feasible handling and treatment processes to develop over-all waste control and abatement systems.

10. That all animal waste research and developmental projects be oriented to obtain cost data to evaluate potential treatment and abatement systems. Economic studies should be conducted to evaluate: (a) the effect of the costs of waste control and abatement on the costs of animal production, (b) the effect of the costs of animal production on the costs of waste control and abatement, (c) the costs that will ultimately be borne by the consumer, and (d) the need for subsidies.

11. That large scale animal production facilities be considered as individual industries subject to State and Federal regulations concerning pollution abatement. Current Federal and State regulations should be reviewed to ensure that they adequately cover pollution caused by animal production facilities.

12. That a forward oriented review be conducted in five years to assess the developments in that time and to develop directions for the future.

PART 1

REASONS FOR THE STUDY

The United States continues to experience a dramatic change in the methods of producing animals for slaughter. Animal production is changing from small, individual farm operations into large scale enterprises. Small animals, such as chickens and hogs, are confined within small areas and buildings in which the environmental conditions are controlled to produce the greatest weight gain in the shortest time. There is an increasing trend for cattle to be finished in similarly controlled areas, dry lot feedlots. Under such conditions, it is not possible for these animals to drop their wastes on pastures where the wastes can be absorbed by nature without adversely affecting the environment.

Animal wastes have become a significant problem compounded by the large volumes to be handled, the nature of the wastes, and frequently the nearness to metropolitan areas. On a volume basis, the total animal waste production in the United States exceeds that produced by the human population by an order of magnitude. Animal wastes have been shown to be a major source of surface water pollution and have been implicated in several cases of ground water pollution. Untreated animal wastes have been involved in the transmission of animal and human diseases.

Past, and to a large extent, current (1967) water pollution control activities are directed at domestic and industrial wastes.

When pollution from these sources is controlled, wastes from agricultural operations still may impart considerable pollutional material to the waters of the nation.

The specific aim of this study has been to develop a forward oriented review of the animal waste problem and its inherent pollution potential. The review will attempt to summarize the present body of knowledge, indicate major problem areas, suggest feasible research and development applicable to the solution of the problem, and identify legislative, educational, and technical areas needing further emphasis. It is hoped that this study will assist in the preparation of approaches and program plans to assure that the pollution control activities of the nation stay ahead of the problems caused by animal wastes rather than attempting to solve the problems after gross pollution and damage have occurred.

PART 2

INTRODUCTION

In recent years the efficiency of agricultural production has greatly increased. This increase, however, has generated or has been associated with a variety of aesthetic and other problems related to the quality of our environment. Efficiency of animal production and quality of the environment are obviously and inescapably tied together. The relationship becomes more pronounced as methods of livestock production and processing change. An adjustment in one of the factors can affect and/or constrain possible or desirable adjustment in the other. Any combination of a given type and scale of livestock operation and given level of environmental quality will have its own benefit-cost relationship. It is obvious that a feasible compromise must be obtained. The concept of a totally unimpaired or totally polluted environment is not meaningful.

Suburban development and the increase in farm technology have sharpened the awareness of the problems of animal waste disposal. With certain animals and in specific areas of the country, large numbers of animals have been concentrated in relatively small areas. The cost of collection, storage, treatment, and disposal of animal wastes in such enterprises may become as important as cost and price determinants of animal production. Methods of handling the animal wastes may adversely affect air, water, and soil quality, and offend the sensitivities of those who dwell nearby.

Animal wastes are one of at least six sources of farm wastes whose management and disposal have become one of the most challenging problems of modern farming. Farm wastes include: (a) human wastes from the farm population; (b) crop residues, (c) food processing wastes, (d) dead animals, (e) agricultural chemical residues, and (f) animal wastes. The problems of animal wastes are related to the handling, treatment, disposal, and management of these wastes. Animal waste is a national problem and not the problem of the isolated livestock producer.

Livestock producers are interested in waste treatment and disposal methods that have low labor requirements, reduce nuisance conditions, and improve sanitation at minimum cost. At present the producers are limited by the lack of available technical information and by the premise that treatment and disposal of animal waste should involve no extra cost nor should it increase the cost of the product.

Historically, animal wastes have been recycled through the soil environment with a minimum of direct release to the water environment. The change to intensive livestock production facilities has weakened the complementary relationship between crop production and livestock production. The relationship is one in which the grain and roughage produced on the land went into the livestock production and the manure from the livestock went back on the land. With increasing concentrations of livestock and alternative sources of fertilizers, the practice of distributing the manure on the land has become doubtful from a profit standpoint. Changes in crop patterns have decreased the area of land available for manure disposal during the growing season.

Separation of animal feeding operations from feed production has caused the disposal of wastes on the land to be less feasible. A number of intensive livestock production units have been constructed without sufficient adjacent land on which the manure can be spread. An increasing number of livestock producers are being faced with large volumes of wastes that have low value and physical, societal and/or economic restrictions that limit the feasibility of recycling animal wastes through the soil environment. One of the largest problems associated with the confinement production of livestock involves the waste disposal.

The number of urban oriented rural residents and open country recreational activities is increasing. This trend, as well as an increasing desire on the part of the public for a more sophisticated environment, will continue. These factors have led to a greater likelihood of problems of agricultural waste disposal in rural and suburban areas. Public pressures for improved waste management systems are increasing. New animal waste collection, transportation, treatment, disposal, and utilization systems are evolving. At present, neither the livestock producers nor the engineers can adequately assess the costs or benefits of such systems. Adequate equipment for handling animal wastes is in the developmental stage. Performance data on equipment for handling animals' excreta have not been determined (1).

Alternative handling and disposal systems frequently create additional problems. If the animal wastes are fluidized, the local water carriage and treatment system is expected to fulfill an additional function. Concentrating and/or drying increases equipment and power costs. Aerobic and anaerobic microbial treatment systems do little to reduce the total volume of material to be handled. Air pollution results from incineration. Many systems do not permit reuse or recovery of the nutrients and energy in the wastes.

In recent years, one of the most positive advances in agriculture has been the mechanization and scientific feeding of livestock. With the market demand for high quality meat, production economies assume greater importance. Confinement feeding of animals has increased significantly in those areas of the nation having an abundant supply of feed grains. To date many of the problems associated with disposal of waste from confined animal feeding have been in corn and grain growing areas of the Midwest.

Historically, the corn belt of the Midwest has been the center of hog and cattle feeding. It is possible that the corn belt will decrease in relative importance as the predominant feeding area as other economic factors assume greater importance and as livestock production becomes more and more of a manufacturing operation geared to convert feed into food in the most efficient fashion.

The livestock industry is undergoing a broad transition with traditional methods and ideas being replaced by new technology and knowledge. The geographic location of livestock population may become less important in the future as feed formulators draw on a large variety of ingredients to obtain a more economical feed ration. Low cost labor and proximity to market may become more important than location of feed grains. This has already been observed with the broiler and egg production industry in the United States.

If such changes take place in the production of other animals, livestock production in areas outside the Midwest will increase and the problems that have been observed with hog and cattle production facilities in the Midwest will be distributed throughout the nation. The increasing demand for meat will cause the problems currently observed in the Midwest to be amplified.

Problems associated with animal waste disposal have existed for a number of years. Past attempts to solve the problems have failed because of attempts to use approaches developed for wastes of other characteristics, to emphasize cheapness rather than adequacy of method, and to consider the problem as separate from other parts of society. No simple or separate solution is likely to evolve.

A program of waste management, with the economic implications understood by the consumer and by society, is necessary. The public must realize that the cost of waste disposal is a part of the price to be paid for a high standard of living. Better solutions will emerge when waste management systems are developed that will give society its desired level of sanitation and society is convinced of the necessity of paying for it.

PART 3

TRENDS IN ANIMAL PRODUCTION

Meat Consumption

The animal waste disposal problem is due not only to the increased population in the United States but also to the increased consumption of beef and broilers (Figure 1). The 1966 per capita consumption values are listed in Table 1. The consumption figures reflect only the usable portion and not the live weight of the animal. It is estimated that about 425 pounds of meat will result from a 1000 pound beef animal after removing fat, bone, and trim. The United States is demonstrating a growing taste for beef and broilers and a slightly decreased taste for pork. The per capita consumption of all meats increased about 15% between 1950-60 while that of beef increased by about 34%. The consumption of beef has become a larger part of the total meat consumption. The average population increase in the United States is about 2.5 million people per year. At the 1966 consumption rates, each additional million people will require another 172,000 beef cattle, 24,500 dairy cattle, and 433,000 hogs.

Livestock Inventory

The distribution and total numbers of livestock in the United States are illustrated in Table 2. The North Central region contains 74% of the hogs, 42% of the cattle, and 39% of the poultry. The South Central and Western regions contain an additional 41% of the cattle. The poultry population is more evenly divided

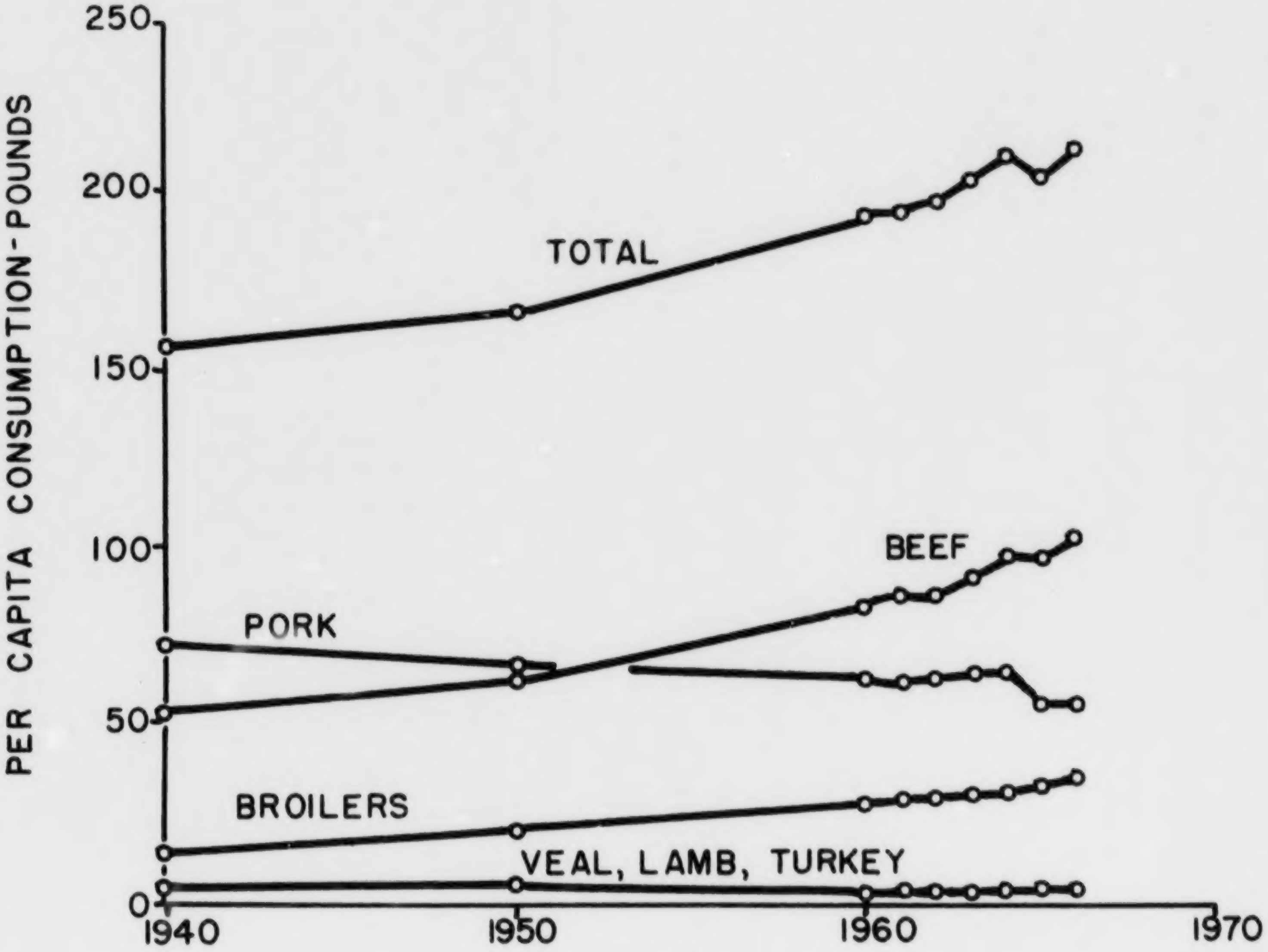


FIGURE 1

PER CAPITA CONSUMPTION OF MEAT
1940-1966 (2)

TABLE 1

PER CAPITA CONSUMPTION OF MEAT
1966

Item	Pounds
Beef	103.7
Veal	4.6
Lamb and Mutton	4.0
Pork	58.1
Broilers	36.0
Turkey	7.8
Total	214.2

throughout the country. Broiler operations are heavily concentrated in the South Central and South Atlantic sections of the country. The states making up the regions noted are indicated on Figure 2.

The historical pattern of the hog, cattle, and chicken inventories is presented in Figures 3 and 4. The fluctuations in inventory represent adjustment to supply and demand factors. Throughout the 25-year period shown, the average number of hogs in the United States has been relatively constant. During the same period, the number of cattle in the nation has increased by about 50% to some 36 million head. An increase of 17 million head, or about 19%, has occurred over the past eight years. The number of broilers has increased dramatically in the last quarter century.

TABLE 2

FARM ANIMAL POPULATION OF THE
UNITED STATES - 1966 (3)
(MILLIONS OF ANIMALS)

Region	Hogs	All Cattle	Dairy Cattle	Chickens Excluding Broilers	Broilers
North Atlantic	0.8	4.8	2.8	51.2	137.2
East North Central	15.6	13.7	4.3	48.9	51.4
West North Central	24.4	34.0	3.7	55.6	45.2
South Atlantic	4.2	7.1	1.4	70.2	987.1
South Central	5.0	26.7	2.5	78.1	1011.3
Western	1.1	19.9	1.8	66.2	99.2
United States	51.2	106.6	16.6	371.4	2332.6

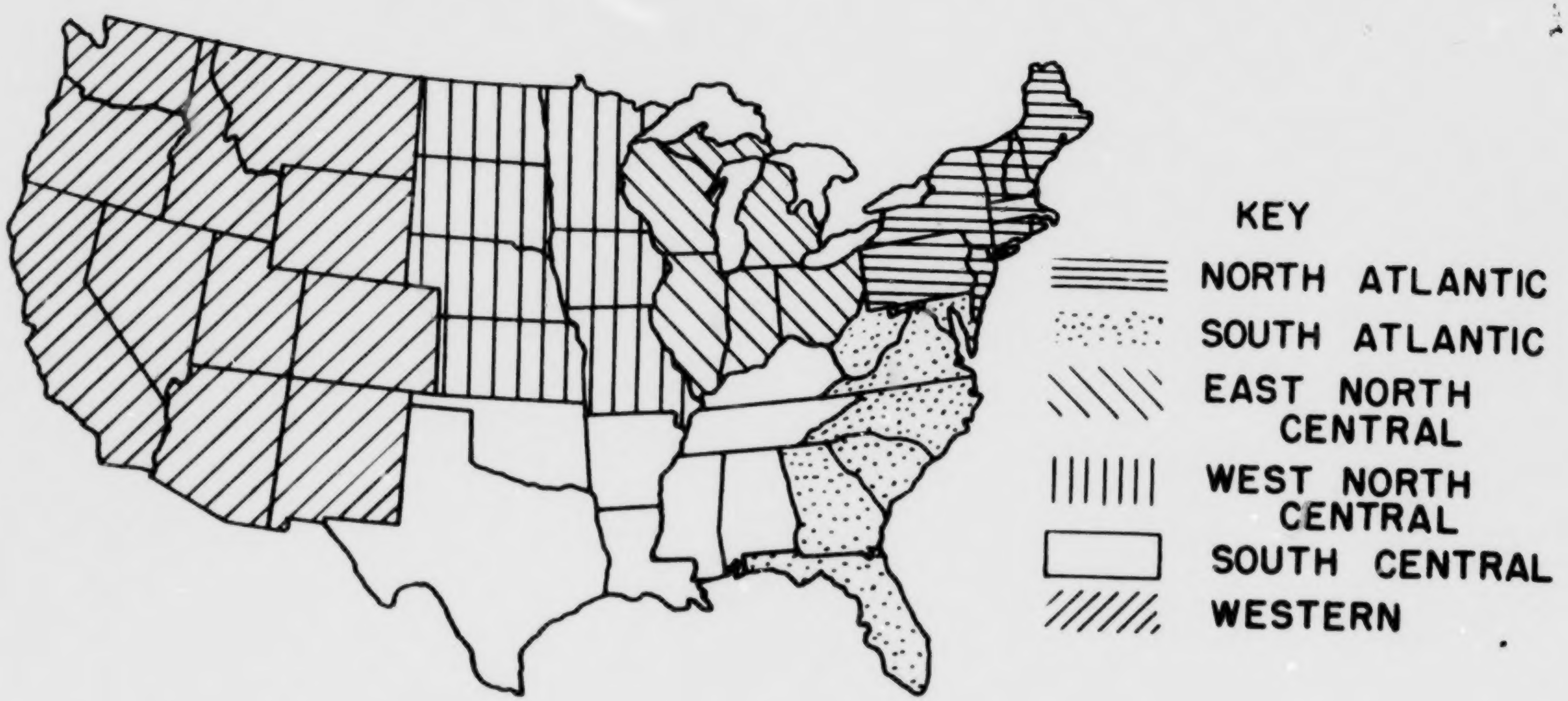

KEY
▤ NORTH ATLANTIC
░ SOUTH ATLANTIC
▧ EAST NORTH CENTRAL
▥ WEST NORTH CENTRAL
☐ SOUTH CENTRAL
▨ WESTERN

FIGURE 2

AGRICULTURAL SECTIONS OF THE UNITED STATES

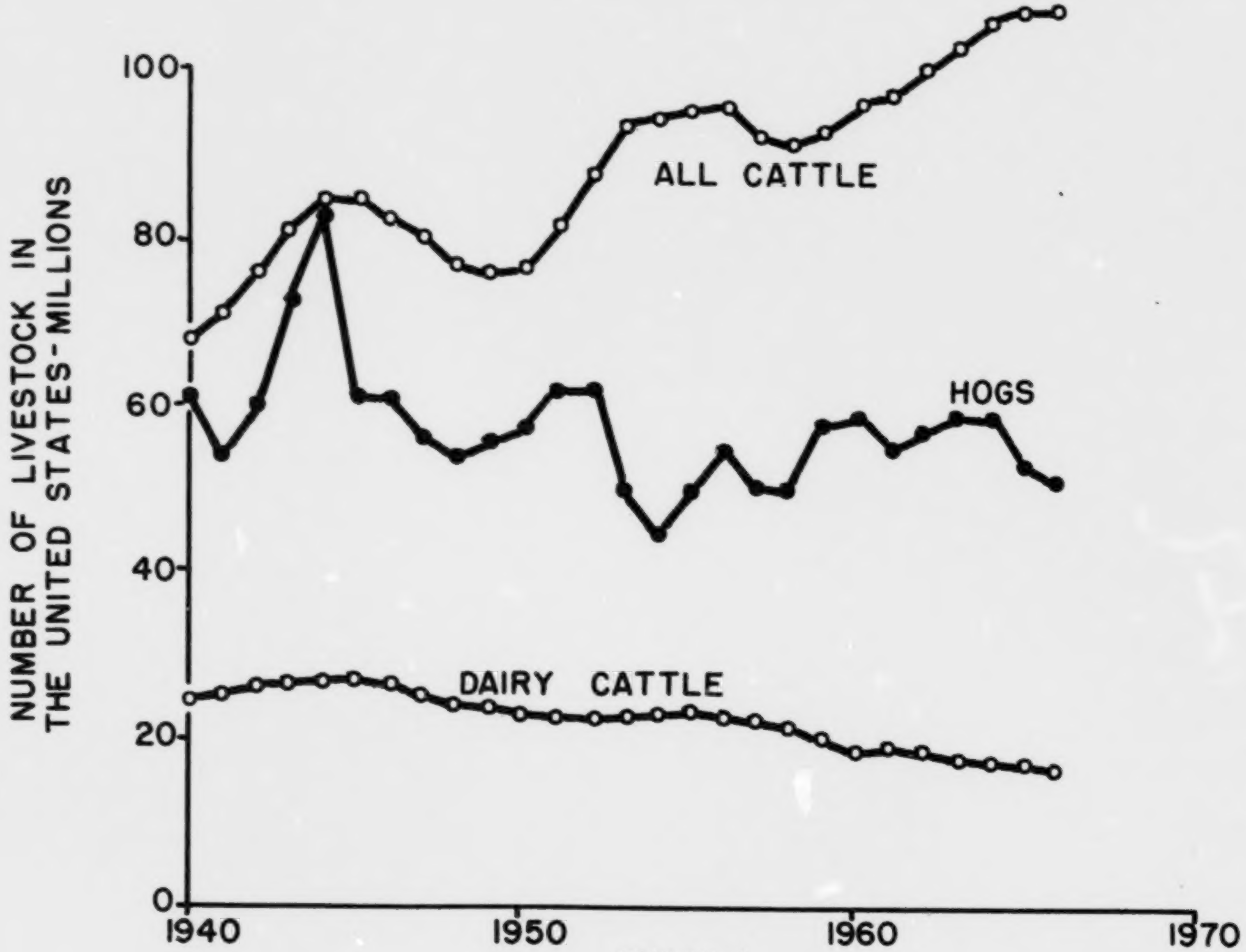


FIGURE 3

HOG AND CATTLE INVENTORY
IN THE UNITED STATES - 1940-1966 (3)

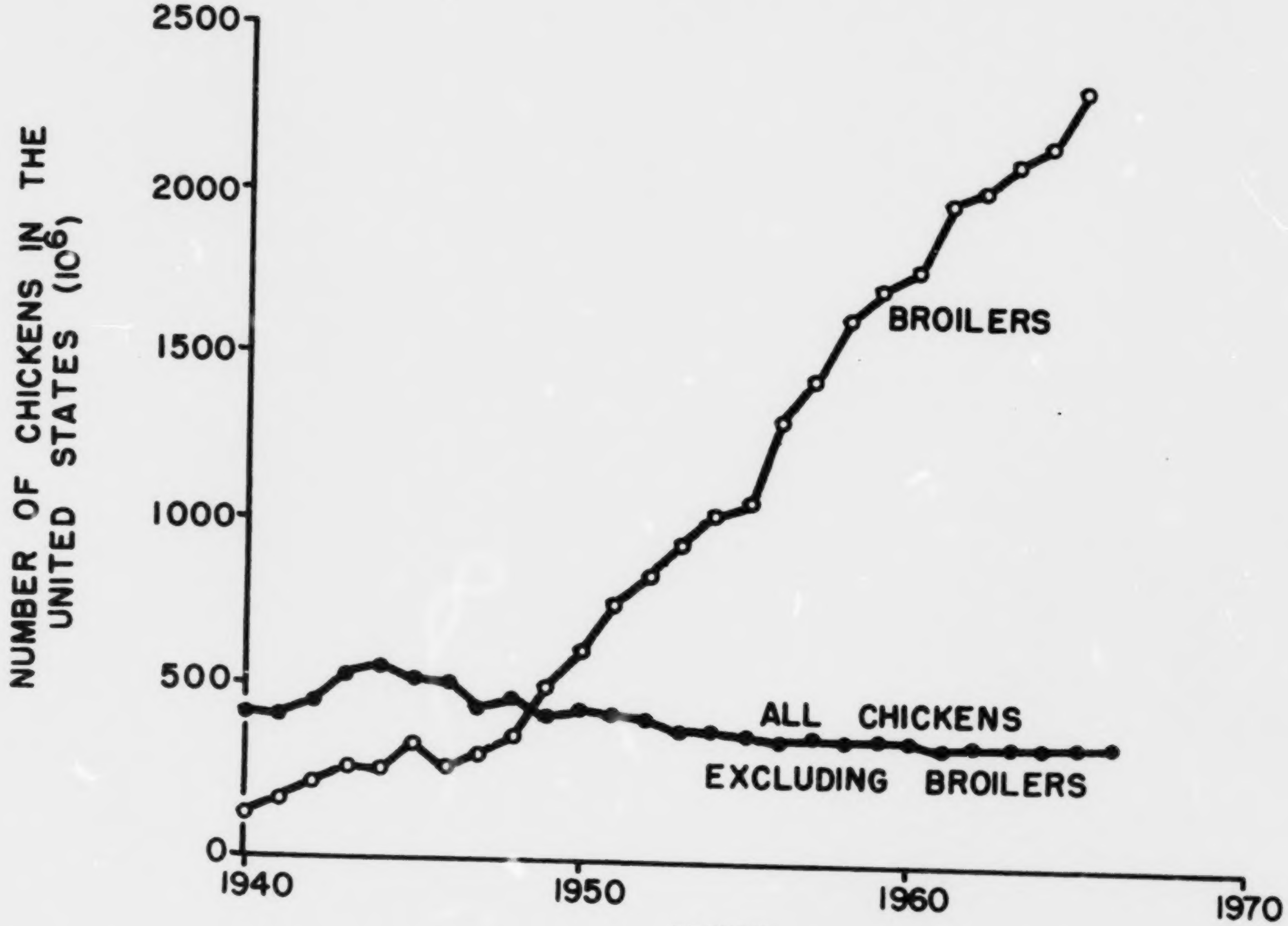


FIGURE 4

CHICKEN INVENTORY IN THE
UNITED STATES - 1940-1966 (3)

TABLE 3

DISTRIBUTION OF BEEF PRODUCTION (4)

Region	Percent of Total Beef Production	
	1959-60	1970
North Central	49.2	48.4
South Central	22.5	22.8
Western	19.3	20.2
South Atlantic	5.5	6.3
North Atlantic	3.5	2.3

Estimates of future beef production suggest that the regional distribution of beef production will vary only slightly. The North Central states of Minnesota, Iowa, Missouri, North Dakota, South Dakota, Nebraska, and Kansas will continue to feed most of the cattle (Table 3). The number of hogs, cattle, and chickens in the United States and the world is expected to increase in the future. In early 1965, the world cattle population was estimated at 1,084 million head, 2% more than in 1964, and 11% above the 1956-60 average. The number in North America was 17% above the 1956-60 average with new highs in the United States, Mexico, Central America, and Canada (5).

Production Units

The trend to confinement feeding of livestock and to increased numbers of animals per production unit is firmly established in the United States. The 3.4 billion dollar poultry industry is a leading example of high intensity type of animal production. In the major poultry producing regions, from 50 to 80% of the laying hens and most broilers are raised in confinement. Most large poultry operations are highly mechanized and are able to handle over 100,000 and frequently over 1 million birds per operation. Offensive conditions produced by poultry operations, particularly the "cage layer" type, have resulted in serious and seemingly insoluble situations. The conditions emanate from poultry houses and manure storage areas, and are created during cleaning, transportation, and spreading of accumulated manure.

Other types of livestock production such as dairy, swine, and beef operations are facing or will face similar problems. The cattle industry illustrates the trend toward confinement feeding of livestock. Specialization has removed cattle from pastures and grass land and has required confinement of large numbers in small areas with an average density of one cow per 50 to 100 square feet. Confinement requires that the feed and water be brought to the animals and they are known as feeder cattle.

The number of cattle on feed for slaughter was over 10 million in 1966 (Figure 5). The rate of increase is large; 66% in the past eight years and 120% in the past 15 years. Over the past eight years the number of cattle on feed in the United States increased at the rate of one-half million head per year. This rate of increase is not expected to slacken in the near future.

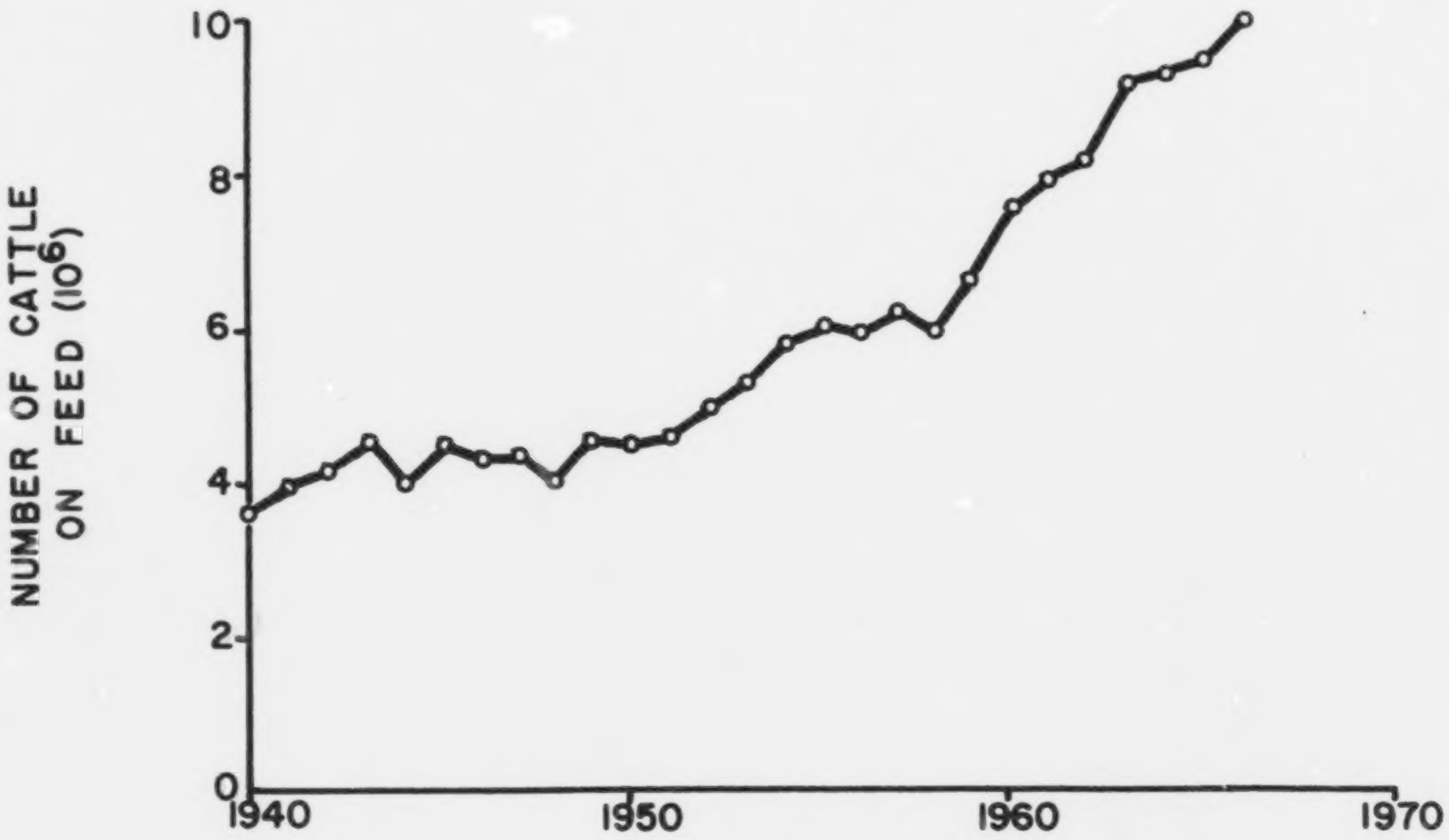


FIGURE 5

NUMBER OF CATTLE ON FEED
1940-1966

Since the 1950's, the commercial cattle feedlot business has been expanding rapidly. Most of the cattle feedlots in the mid-western and western states have capacities for more than 1,000 head. The growth of the industry in Kansas can be used to indicate the expansion (Figure 6). Commercial feeding operations in Kansas, i.e., feeding of cattle in large numbers in confined areas as contrasted to feeding on farms, increased about 1,000% in 10 years. The increase in the past two years has averaged about 50,000 head a year. Commercial feedlots were not a factor in Kansas in the early 1950's. Now they exceed farm cattle feeding in volume.

The amount of cattle on feed can vary throughout the year as many cattle are put on pasture during the spring and summer months and on feed during other portions of the year. The average commercial feeding period is approximately 120 days. Fluctuations in the numbers of cattle in commercial feedlots during the year were less than with farm feeders. Year round cattle feeding operations have reduced the regular seasonal price changes for feed cattle (8).

There is a tendency toward establishing beef processing and packaging facilities in areas near the source of supply and toward decentralization of the packing industry. Feed additives and highly automated feedlot equipment are being used increasingly. These trends will expand the number of cattle on feedlots and the number of feedlots in operation.

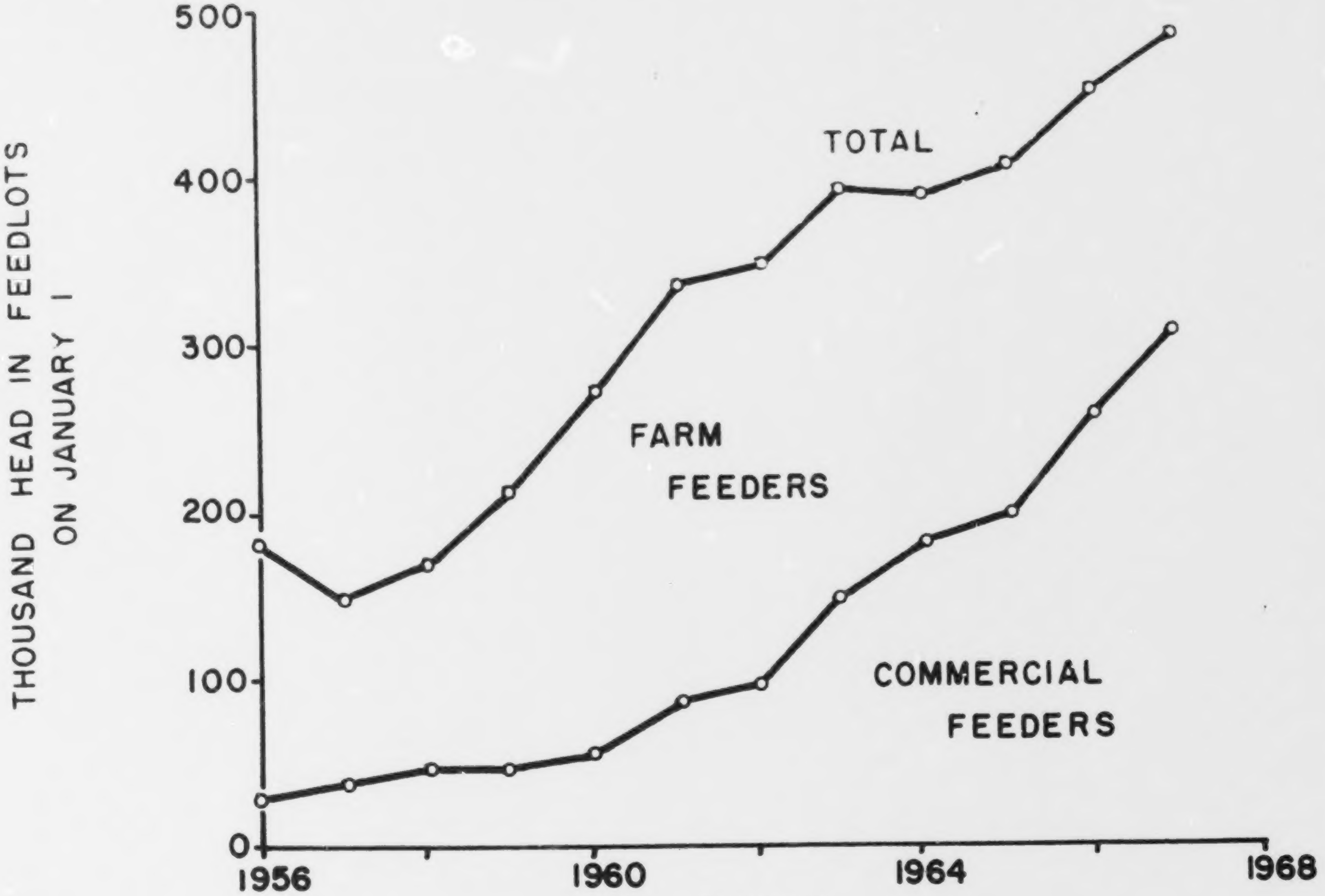


FIGURE 6

CATTLE FEEDING IN KANSAS
1956-1957 (6)

The number and size of commercial feedlot operations throughout the nation have increased. Mechanization, improved production methods, and better nutrition and disease control have enabled the livestock producers to handle more animals without an increase in help. The scarcity of inexpensive farm help also has influenced the trend. A projection of the number of farms in the Pacific Northwest has shown that, although livestock production is expected to increase in that region in the future, the number of feeding operations is expected to decrease (Table 4). The result will be an increasing number of animals per farm.

Certain types of livestock operations have attained optimum size consistent with present technology. Others have not. The downward trend in the number of livestock operations is expected to continue due to the enlargement of existing units and due to the uneconomic operations of farms less specialized and unable to adjust their size. The use of by-product feeds together with the availability of concentrate feeds can be expected to encourage feedlot operations on a larger scale (9).

Studies in California demonstrated an 87% increase in cattle marketings between 1957 and 1963. Virtually all the growth was associated with an increased number of feedlots with 10,000 head or more capacity (10). The changes in the number of feedlots of various capacities in recent years are presented in Table 5. Feedlots of all capacities increased. This trend is expected to increase in the future. The larger lots also tend to market a larger percentage of the cattle.

TABLE 4

FARM AND LIVESTOCK PROJECTIONS--
PACIFIC NORTHWEST--1960-1985 (9)

Farms (thousands)	1960	1965	1970	1975	1980	1985
Livestock	18.4	17.0	16.0	14.9	14.0	13.2
Poultry	3.8	3.3	2.9	2.6	2.3	2.1
Dairy	15.4	14.2	13.2	12.4	11.6	10.8
Livestock Production (million pounds liveweight)						
Cattle and calves	1284	1614	1997	2442	2961	3557
Sheep and lambs	167	163	165	167	167	166
Hogs	154	160	168	178	189	203
Commercial broilers	104	107	119	135	153	172
Turkeys	42	42	42	42	42	42

Other states have experienced an increase in the number and size of feedlots. In 1956, the commercial lots in Kansas with a capacity of 1000 head or more numbered only five. In 1965, there were 65 lots with capacities greater than 1000 head and four lots with capacities of over 10,000 head.

Summary

The population increase in the nation and the increase in the per capita consumption of meat will cause greater numbers of animals to be raised. Because of a growing taste for beef and broilers, the number of cattle and chickens raised for slaughter will increase at a rate faster than the population increase. The number of other livestock raised for slaughter is expected to increase at about the same rate as the population increase.

TABLE 5

NUMBER AND CAPACITY OF CATTLE FEEDLOTS--
1962-64 (11)

Feedlot Capacity	Number of Feedlots		
	1962	1963	1964
1000 - 1999	752	785	808
2000 - 3999	373	388	421
4000 - 7999	179	215	242
8000 -15,999	105	114	120
16,000 -31,999	26	28	34
32,000+	5	7	10

For a variety of reasons, the number of commercial livestock feeding operations will increase in the future as will the numbers of animals per production unit. It has been predicted that the regional distribution of livestock production in the future will vary little from current distributions. The North Central states will continue to feed the majority of the hogs; the North Central, South Central, and Western states will continue to feed the majority of the cattle; the South Central and Atlantic regions will continue to raise the majority of the broilers, and the other poultry populations may be fairly well distributed throughout the nation. Livestock feeding operations will increase throughout the nation.

Because of increased livestock production, increased numbers of production units, and increased numbers of animals per production unit, the problems associated with the handling, treatment and disposal of wastes from these units are just beginning to be realized and will be magnified in the future.

PART 4

MANURE PRODUCTION

General

Agriculture is the biggest producer of wastes in the United States. Livestock on American farms produce about 2 billion tons of manure each year. On a wet basis, an estimated 3 pounds of manure are defecated for each quart of milk produced and from 6 to 25 pounds of manure are produced per pound of livestock weight gain (12). A portion of the total waste production remains in the pasture and rangeland, but an enormous volume accumulates in feedlots and buildings and must be collected, transported, and disposed of in an economical and nonoffensive manner. Manure management is one of the largest problems currently facing the livestock industry.

A review of a large number of publications reveals that the term "manure" may mean any one of a number of things: (1) fresh excrement including both the solid and liquid portions, (2) total excrement but with enough bedding added to absorb the liquid portion, (3) the remaining part of the total excrement after most of the liquid has drained away, (4) the remaining material after liquid drainage, evaporation of water, and leaching of soluble nutrients, or (5) only the liquid which has been allowed to drain from the total excrement.

The water content of each of the preceding materials is highly variable. The moisture content of fresh excrement also changes with the type of feed and environmental temperature. Evaporation of water may occur rapidly under certain conditions. Water is added from rainwater, washwater, or is added specifically to increase the flow and pumping characteristics of liquid manure.

Reported data on manure production vary, depending upon the above factors. Authors frequently do not describe the conditions under which the samples were collected and animals housed.

Effect of Ration

Housing and management conditions are unique for each species of animal and are reflected in the amount and nature of wastes produced. These differences are due to differences in size, diet, and metabolism (13). Simple stomached animals like swine produce feces and urine similar to that of humans. With both swine and poultry, the diets consumed are highly digestible and the amount of excreta produced is relatively small compared to other animals.

The manure from herbivores and ruminants, such as cattle and horses, is different. The bacteria that inhabit the stomach of the ruminant enable these animals to utilize cellulosic feeds. There are, however, certain compounds such as lignin which accompany cellulose in plants and which are difficult to digest in the rumen. Ruminants tend to produce relatively large amounts of fecal wastes when compared to the pounds of feed consumed. These wastes have a different composition than the wastes from simple stomached species. Urinary wastes from herbivores tend to be more alkaline because diets are higher in compounds such as potassium, calcium, and magnesium (13).

One must be cautious in assuming that data accumulated with one species of animal will be applicable to other species. Care must also be taken in assuming that studies made with human wastes will apply to the wastes of animals.

Manure from different classes of animals will have different characteristics. Manure from grass fed animals, growing stock and milk stock is less rich than that from animals being fattened or from work animals liberally fed on concentrates (14). Growing animals and those producing milk retain more nitrogen, phosphorus, calcium, and digestible components of their food for weight gain and milk production than is retained by mature stock being fattened. Animals being fattened are liberally fed to obtain large weight increases. Less nitrogen and minerals are retained in proportion to the amount of food consumed.

Animals in confinement are fed feed of a composition to cause the greatest weight gain in the shortest time. Highly efficient consumption of the feed by the animal is requisite to continuous and rapid weight gain by the animal. Wastes produced under these circumstances will contain more material capable of causing nuisance and pollutional problems than will waste produced under conditions where weight gain is less critical. Animals of the same kind that are fed more concentrates excrete more of the nutritive material because the food contains more. As an example, as the level of protein feeding is raised beyond a certain point, the protein is less effectively digested and more passes into the feces.

The composition of animal manure is dependent upon the digestibility, the protein and fiber content, and the nature of elements of the feed ration. Differences in animal manure can be produced by changes in the environment and by differences in the level of productivity of the stock. Feed additives such as antibiotics, copper, arsenic, grit, or sand will also affect the biochemical properties and the physical characteristics of the manure. After the manure has been excreted, it can be contaminated with bedding, waste feed, and can be diluted with water.

The general nature of animal wastes has been described by Morrison (15):

> The feces of farm animals consist chiefly of undigested food that has never really been within the body proper. This undigested food is mostly cellulose or fiber, which has escaped bacterial action. A portion of the other nutrients usually escape digestion. This may be due to insufficient chewing of such foods as seeds or because some nutrients are protected from the digestive juices through being enclosed in resistant cell walls of cellulose.
>
> In addition to undigested food the feces also contain residue from the digestive fluids, waste mineral matter, worn-out cells from the intestinal linings, mucus, and bacteria. They may also contain such foreign matter as dirt consumed along with the food.
>
> Nearly all of the nitrogenous waste, resulting from the breakdown of protein material in the body, is excreted in the urine through the kidneys, though a trace is given off in the sweat and a more appreciable amount in the feces. In mammals this waste chiefly takes the form of urea, while in birds it is excreted chiefly as uric acid.
>
> A great variety of other end-products of metabolism are likewise eliminated by the kidneys through the urine. Much of the mineral matter is excreted in the urine. However, calcium, magnesium, iron, and phosphorus are voided chiefly in the feces. Small amounts of most of the substances eliminated in the urine are also excreted by the skin through the sweat glands.

Undigested material in the feed and bacterial cells, living and dead, makes up 20 to 30 percent of the solid excrement and contain half or more of its nitrogen content (14). The undigested lignin will combine with the proteins to form a humus comparable with that of soil. More than 25% of the organic matter in cow manure is true humus (14).

The urinary secretion of birds is semisolid and is voided with the feces so that hen manure is a very concentrated product. The urine of hogs makes up a greater proportion of the total excrement and is low in nitrogen and high in phosphoric acid.

It is difficult to predict future types of rations that will be used in animal confinement operations. The controlling factor will be the availability and cost of the various types of feed. As an example, rainfall during most of 1967 was adequate in most states with the exception of a small area of Texas and part of North Dakota. Reliable crop reports indicate a record corn crop along with increases in grain sorghum. The prospects for silage and hay crops are good.

Least cost rations are calculated daily in some of the large livestock production plants such as large commercial feed yards and at least seasonally on farms producing large numbers of livestock. Sorghum grain, corn, and even wheat enter the least cost ration picture. This year (1967) protein supplements are priced in the $90-per-ton range (141). The availability of silage and roughage as well as the feed grains may preclude the use of concentrated feed supplements. A rule of thumb relating good alfalfa hay and a good 40% protein supplement is that four pounds of good alfalfa is the equivalent of one pound of 40% oil meal supplement.

The cost of protein supplements is causing consideration of the use of urea in rations. Use of urea in beef finishing rations is satisfactory up to at least one-third the crude protein source (141). It is possible to remove all roughage from cattle finishing rations by eliminating roughage slowly and increasing grain at the rate of 0.5 pound per head per day (141).

From the waste abatement and control standpoint, it would be highly desirable to reduce the quantity of nondigestible material in the feed. This does not appear to be a controllable factor but will depend upon the cost and availability of the feed. The cost of waste abatement and treatment for the animal producer will introduce another factor that may place greater emphasis on rations with less roughage and nondigestible material and alter the present concept of least cost rations.

There is considerable variation in the characteristics of wastes from confinement feeding operations. These variations occur because of the items described above, the kind of surface upon which the manure accumulates, and the frequency with which the operation is cleaned. In addition, data accumulated more than 10 years ago on the quantity and quality of animal wastes may not represent the characteristics of current wastes because of the changes in feeding, housing, and environment. For example, bedding is rarely used in current confinement feeding operations. The characteristics reported in subsequent subsections represent data from investigations reported since 1960 and do not include bedding or litter.

Physical and Chemical Characteristics

Correlation of reported data is difficult because investigators report information in different units and because not all studies collect data on all parameters. Physical and chemical characteristics of animal wastes, as determined by a number of detailed studies, are listed in Tables 6-11.

Culpin (22) reported that in England the average amount of undiluted manure slurry that resulted from livestock operations, in terms of gallons per day, was: 5.1 per head of dairy cattle, 1.6 per fattening pig, and 6.2 per 100 head of poultry. Wolf (23) indicated that 1 to 2 gallons of manure per hog per day occurred during the finishing period. Taiganides et al. (24) noted that the daily quantity of hog manure varied with the time of the year (Table 12) and suggested a value of 5 pounds of manure per 100 pounds live weight as a daily year round average.

Dale and Day (25) have reported that the daily production of manure from dairy cattle was 7% of the body weight of the animal. The manure contained 87.5% moisture, 12.8 pounds of dry matter in the feces, and 1.08 pounds of dry matter in the urine. Urine made up 30% of the weight of manure, the rest being feces. Sobel and Guest (26) stated that a dairy cow excretes 8% of the body weight

TABLE 6

ANIMAL WASTE CHARACTERISTICS (16)

Item	Chickens	Hogs	Cattle
Animal size (lb.)	4-5	100	1000
Wet Manure (lb./day)	0.12-.39	2.8-9.5	38.5-74.0
Total Solids (% wet basis)	25-48	12-28	13-27
Total Solids (lb./day)	0.05-.10	0.8-1.6	9.5-11.4
Volatile Solids (% dry basis)	74-79	83-87	-
Nitrogen (lb./day)	0.0012-.0057	0.042-.060	0.35-.44
P_2O_5 (lb./day)	0.0010-.0045	0.029-.032	0.11-.12
K_2O (lb./day)	0.0005-.0019	0.034-.062	0.27-.34

TABLE 7

LIVESTOCK WASTE CHARACTERISTICS* (17)

Parameter	Dairy Cattle	Beef Cattle	Poultry	Swine	Sheep
Animal weight (lb.)	1400	950	5	200	100
Manure Production (ft^3/day)	1.3	1.0	0.0062	0.28	0.11
Manure Density (lb./ft^3)	62	60	60	62	65
Moisture (%)	85	85	72	82	77
Nitrogen (% dry solids)	3.5	3.1	5.4	3.3	5.4

*fresh mixed manure and urine

TABLE 8

POULTRY WASTE CHARACTERISTICS (18)

Parameter	Value*
Total Nitrogen	1.8-5.9
Ammonia Nitrogen (mg/l N)	5400
Alkalinity (mg/l $CaCO_3$)	21,000-52,000
pH	6.4-7.0
P_2O_5	1.0-6.6
K_2O	0.8-3.3
Fe_2O_3	1.1
SO_3	0.4-1.2
CaO	4-12
M_SO	0.4-1.2
ZnO	0.8
Total Solids (%)	10-50
Volatile Solids (% dry solids)	70-80

*% of Total Solids except as noted

TABLE 9

NUTRIENTS IN ANIMAL WASTES

Parameter (% of Slurry)	Dairy Cattle	Beef Cattle	Hogs	Poultry	Reference
Nitrogen (as N)	0.13-.42	0.24-.60	0.3-.9	0.41-1.7	19
Phosphorus (as P)	0.06-.09	0.09-.25	0.2-.6	0.30-1.5	19
Potassium (as K)	0.13-.30	0.14-.28	0.2-.4	0.13-1.25	19

Parameter (% Dry Basis)	Cattle	Hog	Sheep	Horse	Hen	
N	0.3 -1.3	0.2 -.9	0.9	0.66	1.8-5.9	20
P_2O_5	0.15-0.5	0.14-.83	0.34	0.23	1.0-6.6	20
K_2O	0.13-0.92	0.18-.52	1.0	0.68	0.8-3.3	20

TABLE 10

CHARACTERISTICS OF ANIMAL MANURES(21)

Animal	Per Cent Moisture	lb./Ton Manure N	P	K	S	Ca	Fe	Mg	Volatile Solids	Fat
Dairy Cattle	79	11.2	2.0	10.0	1.0	5.6	0.08	2.2	322	7
Fattening Cattle	80	14.0	4.0	9.0	1.7	2.4	0.08	2.0	395	7
Hog	75	10.0	2.8	7.6	2.7	11.4	0.56	1.6	399	9
Horse	60	13.8	2.0	12.0	1.4	15.7	0.27	2.3	386	6
Sheep	65	28.0	4.2	20.0	1.8	11.7	0.32	3.7	567	14

TABLE 11

NUTRIENTS IN FRESH ANIMAL MANURES
(lb/1000 gal) (16)

Animal	Ca	Mg	S	Fe	Zn	Boron	Cu
Hen	300	24	26	3.9	0.75	0.50	0.12
Hog	47	6.6	12	2.3	0.50	0.35	0.13
Cattle	17	8.7	5.8	0.3	0.12	0.12	0.04

TABLE 12

SEASONAL VARIATION OF HOG MANURE
CHARACTERISTICS (24)

Parameter	Winter 1961	Summer 1961	Summer 1962
Mean Air Temp (°F)	53	80	64
Water Consumption (lb. day/hog)	-	1.1	1.3
Manure Prod. (lb. day/100 lb. hog)	5.7	2.6	6.2
Total Solids (%)	15.0	18.5	15.6
Vol. Solids (% wet basis)	11.1	15.5	12.9

per day in the form of liquid and solids and that the manure averages 85% moisture. Sobel (27) indicated that the production of manure from dairy cattle ranged from 73 to 143 with an average of 86 pounds per animal per day and contained an average of 87% moisture.

Sobel (27) also reported that the average waste production for leghorn chickens ranged from 0.14 to 0.60 and averaged 0.32 pound per animal a day. The moisture content averaged 75%.

Perkins et al. (28) noted that broiler manure, including floor litter, contained an average of 25% moisture, 1.7% nitrogen, 0.81% phosphorus, and 1.25% potassium. [illegible] manure averaged 40% moisture, 1.3% nitrogen, 1.2% phosphorus, and 1.1% potassium. Papanos and Brown (29) stated that the daily manure of hens raised in confinement was 0.39 lb. Benne et al. (21) estimated that 81% of the nitrogen, 88% of the phosphoric acid, and 95% of the potassium fed to a hen are excreted. Pryor and Connor (30) indicated that the gross energy value of chicken feces ranged from 3.2 to 4.5 calories per gram of dry matter and that the nitrogen content ranged from 0.03 to 0.07 gram of nitrogen per gram of dry matter depending upon the feed ration.

Studies on the physical composition of fresh poultry manure have shown that it contained 75 to 80% moisture, 15 to 18% volatile solids, and 5 to 7% ash. The average particle density was 1.8 and the bulk density was about 65 lb/ft^3. About 50% of the solids were finer than 200 mesh. Based upon 75% moisture the manure contained 1375 B.T.U. per pound of wet manure (27). A white leghorn laying hen produced about 0.09 pound of dry solids per day.

A typical daily materials balance on an 800-lb. beef animal would indicate the following relationships. An average feed ration containing 54 lb. of water and 18.5 lb. of dry matter would result in about 2.5 lb. gain of body weight per day, 34 lb. of feces, and 14 lb. of urine. The excreted wastes would contain 11 lb. dry matter and 37 lb. water. The 18.5 lb. of dry matter in the feed would contain 17.6 lb. of organic matter and minerals including 0.29 lb. K_2O, 0.18 lb. P_2O_5, and 0.42 lb. N. The manure would contain 10 lb. of organic matter and minerals including 0.22 lb. K_2O, 0.14 lb. P_2O_5, and 0.34 lb. N.

Estimates of manure as percent of body weight suggest that average values for dairy cattle, beef cattle, hogs, and laying hens are 8, 6, 6, and 5%, respectively.

Pollutional Characteristics

The previous section attempted to correlate the physical and chemical characteristics of animal wastes as determined by a number of investigators. These characteristics have significance in estimating the quantity and quality of wastes from a variety of animals. For reasons indicated earlier, the data obtained to date are not always comparable.

Individuals concerned with pollution control activities are interested in characteristics that describe the pollutional characteristics, i.e., BOD, COD, suspended solids, and nutrient content of these wastes. Investigators have used at least three different ways to report these data.

The pollutional characteristics can be reported in terms of mg/l of the liquid slurry that results. Since the water content of the waste slurry will vary depending on the quantity of water used in cleaning, spilled by the animals in drinking, excreted by the animals, and by any evaporation or rainfall that occurs between cleanings, values based on mg/l can be expected to vary.

Animal wastes differ significantly from conventional municipal and industrial wastes in that they are solid matter which contains some water. Although the water content will vary, the solids content is dependent only upon the ration fed and the animal species and should be relatively constant per animal. Hence, data frequently are presented as milligram of total or volatile solids.

Other investigators relate the quantity of material to the animal and report data in terms of pounds per head of animal. This latter approach probably is the most realistic and valuable in estimating the pollutional capabilities of a particular production unit.

Traditional analytical techniques for pollutional characteristics such as BOD, COD, and suspended solids were developed for use with liquid wastes. Animal wastes and waste slurries are highly concentrated and manifold dilutions must be made before the traditional techniques can be used. Certain components of the wastes, such as antibiotics and heavy metals that are fed to ensure adequate growth and minimum animal loss, can interfere with some of the analytical techniques. Representative sampling is difficult with wastes as concentrated and heterogenous as animal wastes.

The factors listed in the paragraphs above, and those listed earlier in the section on the effects of rations, indicate why the data from a number of investigators can be in wide disagreement.

The data available from a number of detailed studies are presented in Tables 13-14. Data on waste slurries from dairy or beef cattle operations in the United States are not available since the wastes are generally removed as solid material rather than as a liquid mixture. Additional characteristics of wastes from beef cattle are presented in Table 15.

Interest in wastes from animal production operations in England has increased considerably due to recent legislation that brought farm effluents into the category of trade effluents. The range of results obtained in England are shown in Table 16.

Population Equivalents

The difficulties noted above have led a number of investigators to use population equivalents to estimate the relative contribution of animal wastes. Henderson (45) was one of the earliest to use this approach. His comparisons are presented in Table 17. Population equivalent values can be based upon waste liquid volume, BOD_5, solids, or nutrient contributions. Population equivalent values based upon liquid volume have no meaning with animal wastes due to the variability of liquid volumes from production units. Population equivalents estimated by a number of investigators are presented in Table 18. Population equivalent values are usually based on a contribution of 0.17 lb BOD_5/capita/day and 0.20 lb suspended solids/capita/day in domestic sewage. Population equivalent values are most useful in relative comparisons

TABLE 13

POLLUTIONAL CHARACTERISTICS OF ANIMAL WASTES
WEIGHT UNITS

Total** Solids lb./Day*	Volatile** Solids lb./Day	BOD		COD		BOD/COD	Nitrogen		P_2O_5	Ref.
		lb. Day	lb. lb. VS	lb. Day	lb. lb. VS		Total lb./day	Ammonia lb./day	lb./Day	
				CHICKENS (4-5 lbs.)						
	0.035			0.033	0 93					16
0.063	0.044	0.015	0.34	0.050	1.14	0.30	0.0030	0.0006	0.0026	30
0.066	0.051	0.015	0.29	0.057	1.11	0.26	0.0036	0.0023		31
		0.015-.032								35
0.057-.084		0.006-.010								42
		0.015								47
				SWINE (100 lb.)						
0.80	0.62	0.20	0.32	0.75	1.20	0.27	0.032	0.024	0.025	31
0.97	0.80	0.43	0.54	0.96	1.20	0.45	0.064			24
0.50	0.35			0.47						32
			0.30		1.56	0.19				33
		0.25								35
		0.22					0.07			41
0.71		0.56								42
				DAIRY CATTLE (1000 lb.)						
		1.53	0.13		1.57	0.08				33
10.4	8.3	1.53	0.18	8.4	1.00	0.18	0.38		0.12	31
6.8	5.7	1.32	0.23	5.8	1.02	0.23	0.37	0.23		34
7.5		0.44					0.49			42
				BEEF CATTLE (1000 lb.)						
3.62	3.17	1.02	0.32	3.26	1.03	0.31	0.26	0.11		34
9			0.28		1.15	0.40	0.26			7
				DUCKS						
0.16		0.02-.04					0.08		0.006-.01***	36

*lb./day means lb./day/animal

**Dry solids

***as PO_4

TABLE 14

POLLUTIONAL CHARACTERISTICS OF ANIMAL WASTES--
CONCENTRATION UNITS*

Waste Volume (Gal/day/animal)	BOD (mg/1)	COD (mg/1)	Sus. Solids (mg/1)	Total Solids (mg/1)	Nitrogen (mg/1) Total	Nitrogen (mg/1) NH_3	PO_4 mg/1	Remarks	Ref.
				CHICKENS					
.05	8500-40,000								35
	29,600								37
	13,000	13,200	8,600	15,900	2,020			(1)	38
	24,000	172,000	56,700	180,000	7,660			(2)	38
				SWINE					
	(3) 8,200					500			32
	27,000-33,000	70,000-90,000		6,000-8,000		5,500-7,500			39
	2,250	4,740		695			410	(1)	40
	52,000	143,000		6,240		2,760	4,875	(2)	40
	30,000								41
2.5-5	1,275-13,260								35
				DAIRY CATTLE					
	9,900								37

*Concentration of waste slurry or manure from waste production units

(1) little water conservation

(2) minimum water

(3) antibiotic effect

TABLE 15

WASTES CHARACTERISTICS OF A 900 LB. STEER (7)

60 lb. wet manure per day
(43 lb. feces, 17 lb. urine)
9 lb. dry manure per day
85% moisture content
BOD_5 - 10,000 to 20,000 mg/kg
(1 to 2 lb./steer/day)
COD - 80,000 to 130,000 mg/kg
(9 lb./steer/day)
Volatile Solids - 7 lb./steer/day
Coliform - 230,000/gm
(6 billion/steer/day)
$\frac{\text{Fecal Coliform}}{\text{Fecal Strep}}$ - Less than 0.05

---

of the magnitude of the wastes contributed from domestic and/or municipal sources and from animal waste sources.

Magnitude of the Problem

As Tables 6-18 show, it is difficult to obtain accurate average animal waste production values from published data. Average values are useful to develop order of magnitude information concerning current and potential animal production units.

The average values listed in Table 19 have been estimated by the author using the data in Tables 6, 7, and 13 as representative of animal wastes. These values should be used with an understanding as to why variations exist in the data, as described in previous paragraphs. Suspended solids have no relevance to animal wastes since the latter is a solid rather than a liquid waste. It is meaningful to discuss the total dry solids content of these wastes. Thus, to obtain equivalent per capita values, the per capita total solids contribution of municipal waste water, 0.55 lb. TS/capita/day (48) was used.

TABLE 16

CHARACTERISTICS OF FARM EFFLUENTS

Waste Vol. (gal/animal/ day)	BOD		Suspended Solids		Nitrogen Total mg/l	Remarks	Ref.
	mg/l	lb./animal day	mg/l	lb./animal day			
2.6-6.1	292-3620	0.02-.09	3085-7190	0.18-.19	172-1812	cowshed	42
5.1-28.3	200-2170	0.06-.13	700-3780	0.11-2.5	100-1220	cowshed & dairy	42
7.4-9.5	300-1440	0.02-.14	220-790	0.02-.07	130-1202	cowshed & dairy	43
4.4-9.4	455-2120	0.03-.22	390-1660	0.02-.16	620-4200	milking parlor	42
18.9	472	0.09	817	0.17	100	milking parlor	43
10-30	450-4330					cowshed excl. dung	35
32	1840		3090		1175	farrowing house	43
	610-2000		1490-2380			milking parlor	44

TABLE 17

POPULATION EQUIVALENTS OF ANIMAL WASTES
(BOD_5 Basis) (45)

Species	Human Excrement Baseline	Domestic Sewage Baseline
Man	1.0	0.55
Cattle	6.4	3.5
Hen	0.32	0.17
Sheep	0.57	0.31
Swine	1.6	0.9

Animal wastes rarely contain nitrites and nitrates. Nitrogen found in these wastes is predominately organic and ammonia nitrogen and therefore, total Kjeldahl nitrogen can be used as an accurate measure of the total nitrogen content of these wastes. The nitrogen contribution of domestic wastes has been estimated as 8 to 12 lb./cap/yr (49) (0.033 lb./cap/day). All forms of nitrogen, i.e., organic, ammonia, nitrite, and nitrate nitrogen, may contribute to this concentration. The per capita value of domestic sewage can be related to that of animal wastes since both measurements refer to the total nitrogen content of each type of waste.

The variations in pounds per animal per day (Table 19) reflect the difference in the size of each species of animal and the type of ration fed. The per capita equivalents are relatively constant for a given species of animal when based upon three important pollutional parameters. The greatest correlation generally occurred between nitrogen population equivalent values. The data in Table 19 indicate the

TABLE 18

POPULATION EQUIVALENTS* OF ANIMAL WASTES BOD_5 BASIS

Animal	Reference
Chickens (4-5 lb.)	
11.8	16
11.3	30
12	46
11	47
10-20	18
Swine (100 lb.)	
0.6	16
0.33	24
Cattle (1000 lb)	
Dairy 0.13	34
Beef 0.17	34

*Equivalent animals per capita, i.e., 11.8 chickens contribute the BOD equivalent to one person per day.

TABLE 19

AVERAGE ANIMAL WASTE CHARACTERISTICS

	lb./Animal/Day			Per Capita Equivalent (a) (b)		
Specie	BOD_5	Total Dry Solids	Total Nitrogen (c)	BOD_5	Total Dry Solids	Total Nitrogen
Chickens	0.015	0.06	0.003	11	9.2	11
Swine	0.30	0.90	0.05	0.57	0.60	0.66
Dairy Cattle	1.0	10	0.40	0.13	0.055	0.08
Beef Cattle	1.0	10	0.30	0.17	0.055	0.11

(a) based on average characteristics in municipal sewage: 0.17 lb. BOD/capita/day, 0.55 lb. total solid/capita/day, and 0.033 lb. total nitrogen/capita/day.

(b) number animals equivalent to one person

(c) total Kjeldahl nitrogen

contribution of each species. On a BOD_5 basis, 11 chickens are the equivalent of one person; one hog is the equivalent of 1.8 people; one head of dairy or beef cattle is the equivalent of 7.7 people.

Heavy emphasis is placed upon the control of domestic and industrial waste sources in the United States. To put the animal waste problem in proper perspective, Tables 20 and 21 have been prepared. Table 20 illustrates the human population in the 48 United States, as of the 1960 census, and the population equivalent of the hogs in each state. The percapita values in Table 19 were used for this purpose. Seven midwestern states have population equivalent hog populations greater than the human population of those states. Similar analyses of all chickens, excluding broilers, indicated that no state had a population equivalent chicken population greater than the human population. The population equivalent cattle population of many states exceeded the human population of those states.

Table 21 illustrates the equivalent per capita population of the most important animal species. It is obvious that the wastes from animals represent a potentially large pollution problem.

The data used to prepare Tables 20 and 21 were the farm census figures prepared by the U. S. Department of Agriculture (3). Many animals included in this census are reared in areas where the wastes can be absorbed by the land without creating pollutional

TABLE 20
EQUIVALENT POPULATION* OF ANIMALS (1960)

State	Human Population	HOGS		
		BOD Basis	Total Dry Solids Basis	Total Nitrogen Basis
Alabama	3267	2060	1900	1720
Arizona	1302	58	52	48
Arkansas	1786	860	800	720
California	15717	680	630	565
Colorado	1754	395	370	330
Connecticut	2535	38	35	32
Delaware	446	63	60	52
Florida	4952	720	670	600
Georgia	4043	3200	2950	2670
Idaho	668	270	250	225
Illinois	10081	13500	12500	11200
Indiana	4662	8900	8300	7420
Iowa	2758	23400	21800	19500
Kansas	2179	2120	1950	1770
Kentucky	3038	2650	2460	2210
Louisiana	3257	610	560	510
Maine	969	40	36	33
Maryland	3100	335	310	280
Massachusetts	5149	243	225	202
Michigan	7822	1440	1330	1200
Minnesota	3414	6500	6000	5400
Mississippi	2178	1400	1300	1160
Missouri	4320	7600	7100	6350
Montana	674	270	250	235
Nebraska	1411	4500	4140	3750
Nevada	285	18	17	15
New Hampshire	608	23	21	19
New Jersey	6067	3100	2850	2580
New Mexico	951	100	93	84
New York	16783	240	220	200
North Carolina	4556	2730	2500	2280
North Dakota	633	520	480	435
Ohio	9706	4850	4500	4050
Oklahoma	2329	850	790	710
Oregon	1769	330	310	275
Pennsylvania	11319	1000	930	835
Rhode Island	859	18	17	15
South Carolina	2382	1080	1000	900
South Dakota	681	2400	2200	2000
Tennessee	3267	2620	2400	2180
Texas	9580	2000	1860	1670
Utah	891	122	115	102
Vermont	390	20	18	16
Virginia	3967	1240	1150	1040
Washington	2853	260	240	216
West Virginia	1860	200	185	165
Wisconsin	3952	3500	3300	2940
Wyoming	330	63	60	53

*In terms of equivalent waste contribution from people, units are in terms of thousands of people or equivalent people.

TABLE 21

EQUIVALENT POPULATION* OF ANIMALS
IN THE UNITED STATES (1960) (MILLIONS)

Human Population	Specie	BOD Basis	Total Dry Solids Basis	Total Nitrogen Basis
179.3	All Cattle	655	1,600	1,040
	Hogs	106	74	89
	Chickens	33	40	33
	Broilers	163	195	163

*In terms of equivalent people

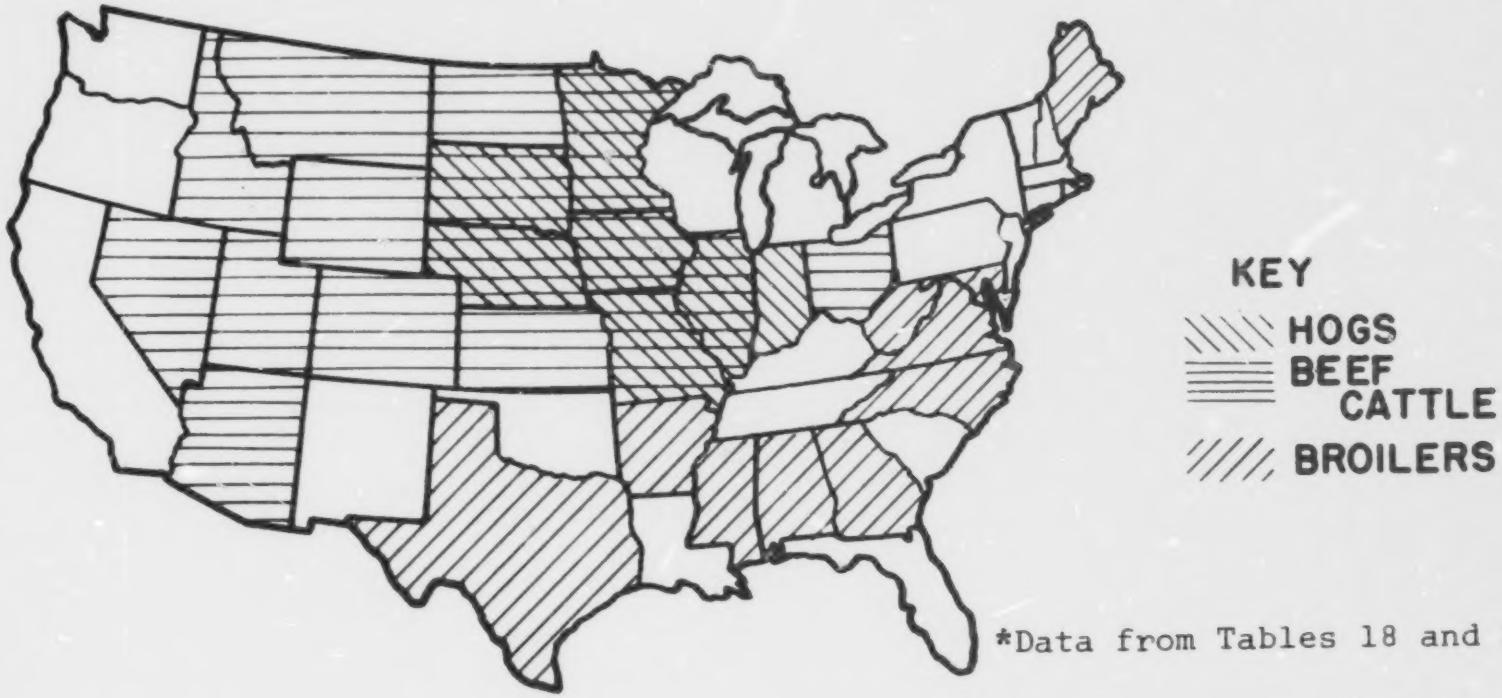
problems. Wastes caused by animals in confinement are likely to cause the greater pollutional problems. The magnitude of the potential problem caused by these confinement operations can be estimated by viewing the statistics of beef feeder cattle and commercial broiler chickens produced by such operations. Table 22 indicates that the states having a per capita equivalent population of these animals greater than the human population.

Figure 7 depicts the regions having the greatest potential for animal waste problems. Broiler operations predominate in Atlantic and Southern states while hog and beef cattle operations predominate in the Midwest and Western states. With the population increase and the increased per capita consumption of beef and chicken, confinement operations can be expected to

TABLE 22

EQUIVALENT POPULATION OF ANIMAL WASTES GREATER THAN HUMAN POPULATION (1960)

State	Beef Feeder Cattle	Commercial Broiler Chickens
Alabama		*
Arizona	*	
Arkansas		*
California		
Colorado	*	
Connecticut		
Delaware		*
Florida		
Georgia		*
Idaho	*	
Illinois	*	
Indiana		
Iowa	*	
Kansas	*	
Kentucky		
Louisiana		
Maine		*
Maryland		*
Massachusetts		
Michigan		
Minnesota	*	
Mississippi		*
Missouri	*	
Montana	*	
Nebraska	*	
Nevada	*	
New Hampshire		
New Jersey		
New Mexico		
New York		
North Carolina		*
North Dakota	*	
Ohio	*	
Oklahoma		
Oregon		
Pennsylvania		
Rhode Island		
South Carolina		
South Dakota	*	
Tennessee		
Texas		*
Utah	*	
Vermont		
Virginia		*
Washington		
West Virginia		*
Wisconsin		
Wyoming	*	


KEY
▧ HOGS
▤ BEEF CATTLE
▨ BROILERS

*Data from Tables 18 and 20

FIGURE 7

STATES IN WHICH THE EQUIVALENT POPULATION OF ANIMAL WASTES IS GREATER THAN THE HUMAN POPULATION (1960)* increase in the states noted in Figure 7 as well as in other states. Problems associated with other animal wastes will increase in these states as well.

Summary

Estimating animal manure production is difficult. Published values vary due to differences in: (1) housing and management practices, (2) type of rations fed, (3) analytical techniques employed, and (4) manure handling and collection techniques. Future investigators dealing with any aspect of the animal waste problem should be encouraged to report the conditions under which the animals were fed and housed and the manner in which the samples were taken and analyzed so that continuing correlation of waste production can be made.

It is doubtful that any single study on animal waste characteristics would be as valuable as comprehensive information obtained from a multitude of independent investigations studying a number of factors under widely varying conditions. It would be valuable to have a detailed study on the applicability of the traditional physical, chemical, and biological analytical techniques to animal wastes. It is unlikely that this information will be included in conventional animal waste studies. The traditional techniques were developed for liquid wastes and their applicability and accuracy when used with solid wastes, such as animal wastes, remain largely unknown. New analytical techniques may be needed.

The evaluation of animal waste characteristics conducted in this report is summarized in Table 19. These parameters represent average values derived from the published data and have greatest value when used as guides to estimate the potential wastes generated from a production unit.

The trend toward increasing confinement animal feeding will create greater concentrations of wastes and should create wastes of greater pollutional nature as the feed rations slowly change to feeds that contain less roughage and more biodegradable material.

A number of States have a per capita equivalent animal population greater than the human population. These are the States where problems generated by animal wastes will likely be the greatest. This does not infer that problems will not occur in other states. Localized problems may occur whenever concentrated animal production units are developed. As indicated in Table 5, about half of the beef cattle feedlots have capacities for 2,000 head, and 10,000-head lots are not uncommon. These lots will produce wastes, on a total solids basis, equivalent to that from communities of approximately 36,000 and 182,000 population, respectively. Broiler operations may house from 100,000 to 1,000,000 birds. These operations produce wastes comparable to communities of approximately 10,000 and 100,000 population, respectively.

Animal waste production in the United States exceeds that of human population. The animal wastes have a large pollutional potential. An enthusiastic, vigorous, and concerted effort to abate and control problems arising from animal production units is justified.

PART 5

POLLUTION AND NUISANCES

Introduction

A variety of educational activities has created a growing public awareness that the rivers and streams of the nation should be made and kept reasonably clean. These programs have emphasized the control of municipal and industrial pollution sources. The pollution hazards inherent in the disposal of animal wastes are less well understood even by the professionals in the agricultural and sanitary engineering fields.

Data describing potential and actual pollution caused by animal wastes are accumulating. Henderson (45) noted that, under certain conditions, agricultural land runoff may make municipal contributions appear insignificant. Based on the evaluation of only the contribution from cattle, hogs, chickens, and sheep, it has been postulated that a flushing flow over 1% of the Missouri River drainage basin would contribute pollution equivalent to that from a population of 2.9 million (51). Discharges of this type would severely tax the resources of the receiving stream since they represent a slug load to the stream. More definitive studies are reported in the following paragraphs.

Organic Pollution

Until the animal wastes enter ground or surface waters, they rarely represent a serious water pollution problem. Such wastes usually stay within the confinement area until the area is cleaned or, in some cases, until runoff washes them away. The water pollution problem associated with animal wastes frequently is a drainage problem. Runoff from confinement areas and from land used for disposal of the waste occurs during and following rainfall.

Farm animal wastes can be a major source of water pollution. Studies on Long Island have revealed that the navigable waters of Moriches Bay and part of Great South Bay are polluted by bacteria, suspended solids, and nutrients that have resulted from land drainage. Major sources of pollution are the duck farms lining the shores (36). Closing of these areas to shellfish operations has caused an economic injury in excess of 2.5 million dollars annually to the shellfish industry. Pollution of these waters has resulted in an unsightly appearance, production of objectionable odors, excessive algae and aquatic plants, and has adversely affected recreational use of the waters.

Actual documentation of pollution caused by animal wastes is rare due to the variable nature of rainfall and runoff relationships. The effect of such pollution is apparent in the number of fish kills that have occurred. The fish kills attributable to animal wastes in Kansas and in the nation are presented in Table 23. Most of the fish kills caused by animal wastes occurred in in Kansas. This suggests a greater awareness by Kansas officials of the pollution caused by animal wastes and not that the problem is unique to Kansas. Animal wastes killed 82 and 99.5 percent of

TABLE 23

FISH KILLS ATTRIBUTED TO ANIMAL WASTES (52-54)

	1964	1965	1966
	Number of Kills		
Kansas	15	5	15
United States	29	29	--
	Fish Killed* (Thousands)		
Kansas	1,100	571	1,000
United States	1,156	617	--

*By animal wastes

the fish killed in Kansas in 1964 and 1965, respectively. Spring rains in Kansas in 1967 caused tons of cattle feedlot waste to enter the receiving streams killing an estimated 300,000 to 500,000 fish.

Many of the fish kills in Kansas have occurred upstream of completed or contemplated multipurpose reservoirs. Entrapment of such pollution in these reservoirs raises interesting questions relative to possible aquatic growths and water quality changes in reservoirs, recreational use of the waters and shore, effect on downstream water users, and effect on reservoir operations. In the spring of 1967, the State Health Director of Kansas issued an order banning body contact sports in the John Redmond reservoir, a reservoir that had been the scene of a number of fish kills caused by runoff from cattle feedlots on tributary rivers.

The runoff from cattle feedlots can be potent. Miner et al. (55) demonstrated that feedlot runoff is a source of high concentrations of bacteria normally considered as indices of sanitary quality, and that the greatest pollutant concentrations were obtained during warm weather, during periods of low rainfall intensity, and when the manure had dissolved by water soaking. Ammonia nitrogen concentrations ranged from 16 to 140 mg/l, suspended solids concentrations ranged from 1500 to 12,000 mg/l, and COD concentrations ranged from 3000 to 11,000 mg/l in the runoff from their studies. Average chloride and phosphate concentrations were 300 and 50 mg/l, respectively, for lots with concrete surfaces. The authors developed equations to predict the COD and nitrogen content of feedlot runoff based upon the above factors.

Additional characteristics of cattle feedlot runoff are presented in Figures 8 and 9. The information in the Figures and that noted above indicate why large and extensive fish kills have occurred when cattle feedlot runoff has entered a receiving stream.

Smith and Miner (57) obtained water quality measurements on streams and rivers when cattle feedlot runoff occurred and noted the slug effect of such runoff (Table 24). They found that feedlot runoff and streams polluted with such runoff showed high ammonia concentrations, and that the ammonia associated with feedlot pollution tended to be detectable before other parameters appeared. Considerable lengths of stream and rivers were found to be devoid of oxygen due to pollution caused by feedlot runoff. The slug

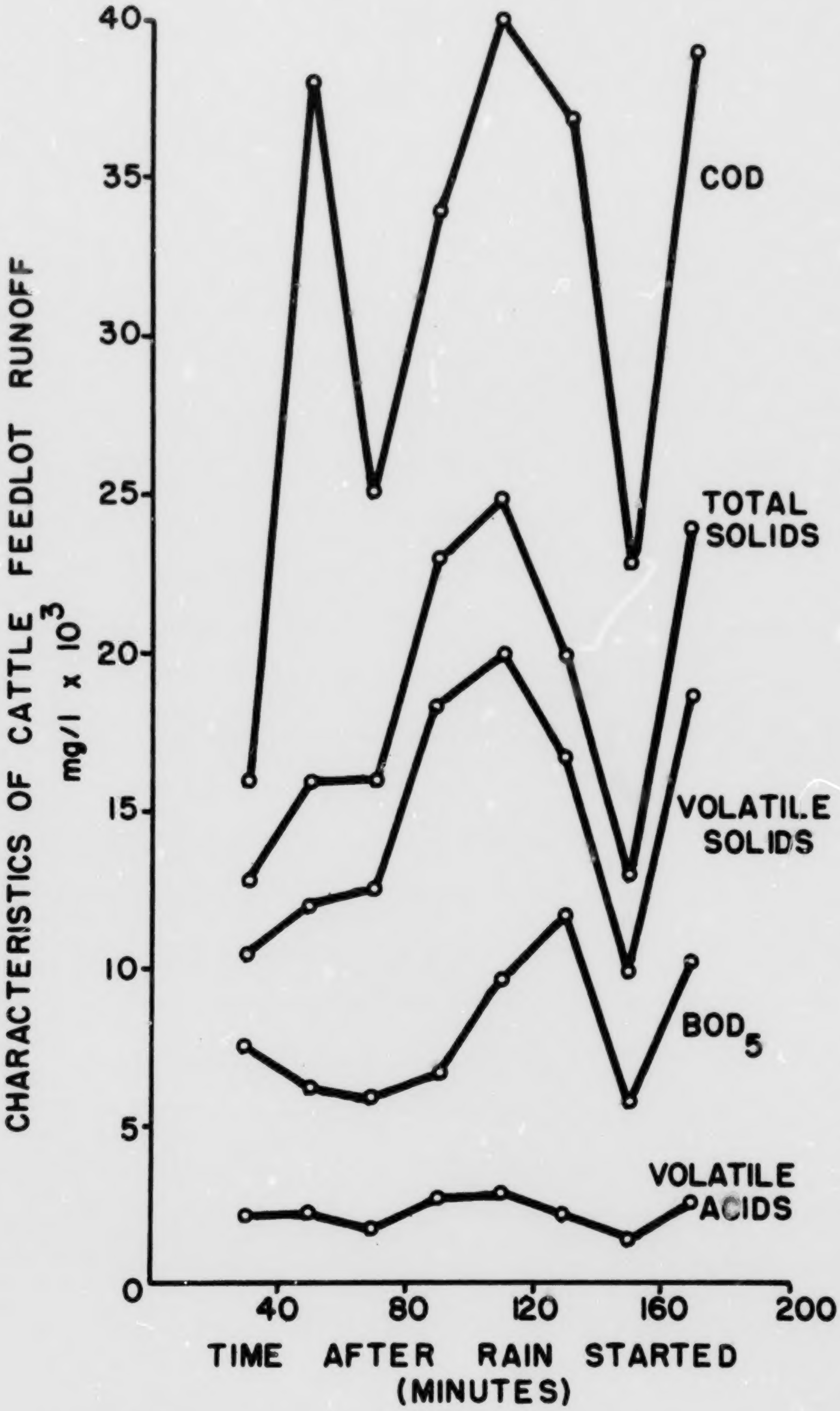


FIGURE 8
CATTLE FEEDLOT RUNOFF
1.74" RAIN/24 HOURS (56)

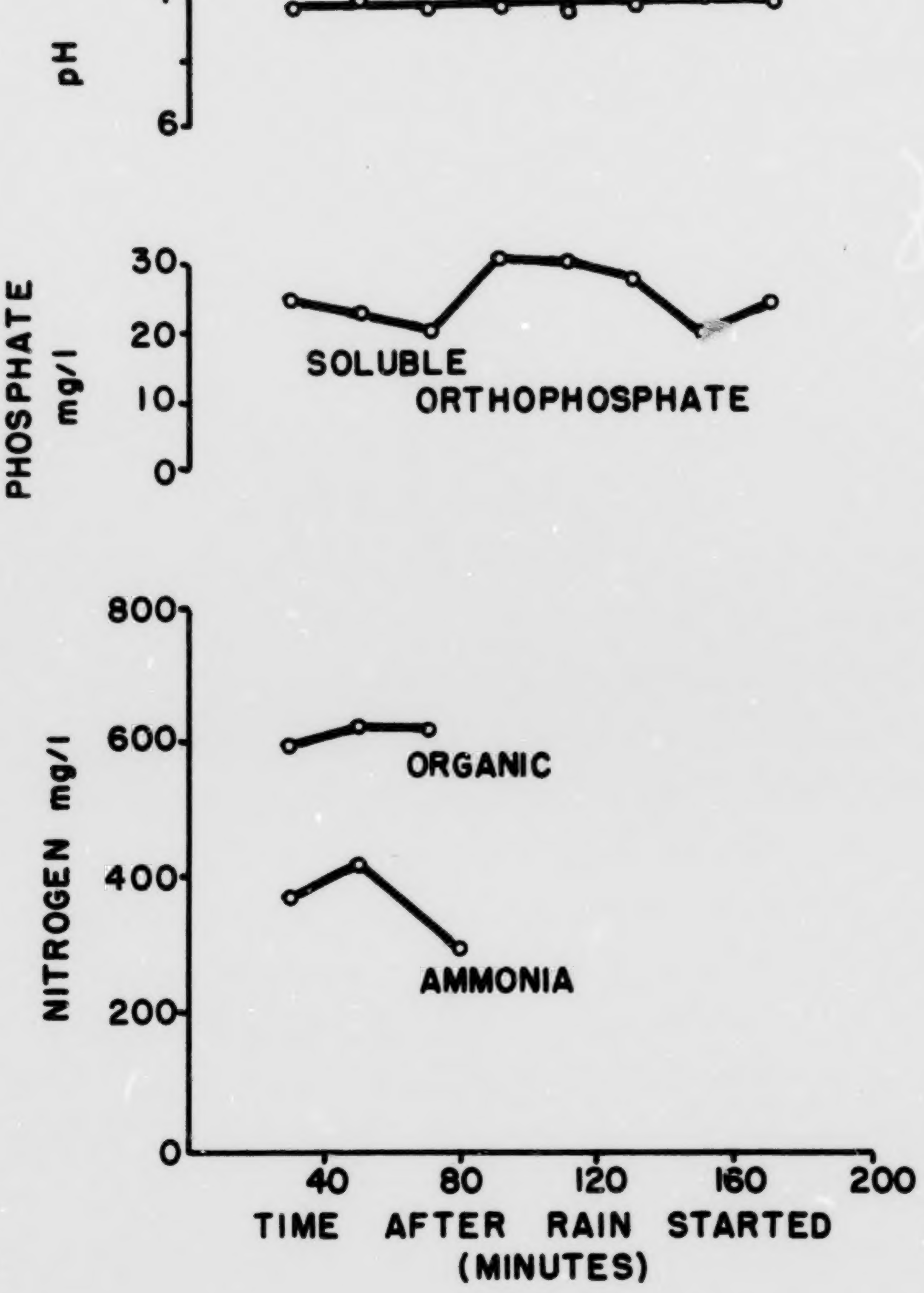


FIGURE 9
CATTLE FEEDLOT RUNOFF
1.74" RAIN/24 HOURS (56)

TABLE 24

FOX CREEK NEAR STRONG CITY, KANSAS, NOVEMBER 1962
WATER QUALITY PARAMETERS (mg/l) (57)

TIME	DO	BOD_5	COD	Cl	NH_3
Avg. Dry Weather	8.4	2	29	11	0.06
After Rainfall					
13 hours	7.2	8	37	19	12.
20 hours	0.8	90	283	50	5.3
26 hours	5.9	22	63	35	
46 hours	6.8	5	40	31	0.44
69 hours	4.2	7	43	26	0.02
117 hours	6.2	3	22	25	0.08

effect of such runoff provides little warning to downstream users and traps game fish in the polluted waters.

Where animals are housed in the open, such as cattle feedlots and duck farms, runoff has caused significant pollution. Pollution caused by runoff is reduced when the animals are completely housed as is the case in most hog, broiler and dairy operations. In the latter cases, pollution has been the result of accidental or willful disposal of the accumulated wastes in adjacent bodies of water. Complete confinement will reduce the runoff pollution caused problems.

Inorganic Pollution

High nitrogen concentrations in ground and surface waters are another pollution problem associated with confinement animal operations and feedlot runoff. Keller and Smith (58) indicated that

30 to 50% of the rural water supply samples they studied in Missouri contained more than 5 ppm nitrate-nitrogen, a concentration high enough to be considered important to livestock production. They indicated that the main contaminating source both in distribution and concentration was waste matter at sites of animal habitation. Soil containing 2000 lb. of nitrate-nitrogen per acre was found below feedlots. Standard surface soils contained about 50 to 150 lb. nitrate-nitrogen per acre. They noted that contamination from nitrates remained even after an area was abandoned from animal use. Barnyards, feedlots, and manure piles have been indicated as sources of excessive nitrate nitrogen in shallow wells in Nebraska and Illinois (58,60).

The high concentrations of ammonia nitrogen in feedlot runoff (55,57) and lagoon effluent (61) contribute to the nitrate concentration in surface waters when the ammonia is oxidized. In addition, the high nitrogen concentrations contribute to the algal growth potential in the receiving waters. Nitrogen in water can be a problem due to the toxicity of nitrates to babies and livestock and due to the stimulation of aquatic plants in receiving waters.

The nitrogen and phosphorus contribution from various sources (49) has recently been estimated and is presented in Table 25. The annual contributions indicate the relative magnitude of the various waste sources and indicate that domestic and industrial wastes are not the leading contributors of nitrogen and phosphorus. Equal if not more attention should be given to problems from agricultural runoff and animal wastes.

TABLE 25

ESTIMATE OF NUTRIENT CONTRIBUTION FROM VARIOUS SOURCES (49)

Source	Nitrogen 10^6 lb./yr	Phosphorus 10^6 lb./yr
Domestic Waste	1100-1600	200-500
Industrial Waste	1000	-
Rural Runoff		
Agricultural land	1500-15,000	120-1200
Non-agricultural land	400-1900	150-170
Farm Animal Waste	1000	-
Urban Runoff	110-1100	11-170
Rainfall	30-590	3-9

The nitrogen contribution from farm animals can be estimated from the data in Tables 2 and 19. The nitrogen content of the waste from hogs, all cattle, and chickens including broilers in 1966 was 2.5, 37 and 8 million pounds per day. The total contribution from the above animals is approximately 17,300 million pounds a year. Not all of this quantity reaches the receiving waters.

Average chloride concentrations from cattle waste installations have ranged from 30 to 2500 mg/l (55,56). The lower concentrations were associated with runoff while the higher concentrations were associated with effluents from animal waste treatment facilities. The average salt intake for cattle ranges from 1 to 2.5 lb. per month depending on season and type of feed. The salt content of an average cattle ration is about 1 to 2 lb./day (15). Most of the salt intake is excreted in the urine and feces. With the average head of cattle excreting about 60 lb. of urine and manure per day, the chloride content of liquid slurries and effluents from waste treatment facilities can be high.

Health Aspects

The list of infectious disease organisms common to man and other animals is lengthy, including a number that can be water borne (62). When drainage or runoff from animal production units reaches a water course, a potential chain for the spread of disease has been initiated. Although documentation of water borne disease transmission from animal to man is rare, such transmission has been noted. Several young people swimming in the Cedar River, Iowa, were infected with leptospirosis while swimming downstream from an area where leptospirosis infected cattle had access to the river (63).

Salmonella organisms have been isolated from fecal specimens, runoff from animal confinement operations, carcasses of dead animals, and from waterholes from which the animals drank (36, 64-67). Two organisms, *S. dublin* and *S. typhimurium* were the salmonella organisms most commonly found in the cattle and contaminated water investigated. *S. dublin* is essentially a pathogen of cattle but can cause meningitis and septicaemia in humans. Apparently children are more susceptible than adults. *S. typhimurium* can infect practically all species of birds, animals, and man with equal facility.

Many infections of farm livestock are spread in their excreta. The disease potential inherent in the use of manure slurry systems to dispose of wastes on farm land is unknown. It is possible that under certain circumstances, the use of such systems could increase the disease hazard to man and animals. The possible presence of animal pathogens in runoff and effluent from waste treatment systems suggests that caution be exercised in reusing such water in and around animal production units.

Coliform organisms are used as an index of water-borne disease hazard. The per capita coliform output for cows, hogs, sheep, and ducks ranged from 2.9 to 9.3 times that of man (68). Fecal coliform organisms are more indicative of pollution from humans and animals. Fecal streptococci have also been suggested as a reliable and definitive measure of human or animal pollution.

The coliform concentration in the effluent from duck holding facilities has ranged from 6 to 60 million per 100 ml (36). Enterococci counts of bovine manure have ranged from 3.5 to 17 million per gram while coliform counts have ranged from 0.3 to 0.6 million per gram (34). The total coliform, fecal coliform, and fecal streptococus counts in cattle feedlot runoff averaged 105, 72, and 324 million organisms per 100 ml, respectively, for concrete surfaced lots (55). Total coliform and enterococci counts in the supernatant from hog waste treatment lagoons averaged 1.4 and 1.2 million organisms per 100 ml, respectively (32).

The ratio of fecal coliform to fecal streptococci can be used to delineate between human and animal pollution. The ratio in human and domestic wastes has been shown to be over 4 while for fecal material from animals, the ratio was less than 0.6 (69). A ratio of 0.2 has been noted in cattle feedlot runoff (55). The bacterial types found in a lagoon treating bovine wastes have led one group of investigators to conclude that the pollutional potential for true *E. coli* and *S. faecalis* in lagoon waters is minor (34).

Histoplasmosis is a disease caused by a fungus that thrives in collected bird droppings. The symptoms are similar to those for influenza and pneumonia. Although most of the patients recover, deaths can occur. Dust generated by cleaning will disperse the fungus. Frequent waste removal, and keeping the wastes wet will minimize the transmission potential. The disease has not been shown to be a problem with wastes from animals other than birds.

Additional Problems

Flies can be a nuisance in and around animal production and waste treatment facilities. Hart *et al.* (70) found that flies were attracted to freshly excreted waste if the moisture content ranged from 55 to 85%. Flies were found to accumulate at feeding areas. Fly production was controlled by covering manure piles with 3 to 4 inches of dried manure or with a plastic tarpaulin. Effective fly control was obtained by spreading the fresh manure in one inch layers and stirring daily with a rotary tiller.

Odors are another nuisance associated with animal production facilities. While some odors are inevitable near such facilities, obnoxious odors can be controlled by proper sanitation in the production facilities and by proper operation of treatment facilities.

Wastes from animal production waste treatment facilities are colored. The color is similar to that of medium to strong tea (7,20,71). The yellow to brown color of the wastes appears to be unaffected by biological treatment. An effluent with this characteristic may be aesthetically undesirable and, depending upon the amount of dilution in the receiving stream, may cause color problems for downstream water users.

The color apparently is caused by chemicals in true solution since it cannot be removed by filtration through a membrane filter with a pore diameter of 0.45 micron. The materials responsible for color in waters and waste waters are a heterogeneous mixture of organic compounds yielding fulvic, humic, and hymatomelanic acid as well as hestianic acid (72,73). Such compounds are part of the humus found in soil and result from the decay of organic material. The presence of similar colored material in animal waste systems is not unexpected in light of the humus formation within the animal, as previously discussed, and possibly within the anaerobic and aerobic systems used for waste treatment.

Summary

Pollution caused by animal production facilities can be as detrimental to a receiving water body as wastes from any other industry. Production facilities and confinement feeding have been developed with little planning and concern for the nuisance and pollutional characteristics inherent in the facilities. Many of the most obvious cases of pollution could have been prevented if the facilities were located in areas less susceptible to runoff and to accidental release of wastes directly to receiving streams. The economics of pollution and nuisance control in animal production is an important factor and may mean the difference between success and failure for the facility.

Information is lacking on the pollution potential inherent in the spreading of wastes on land. Both ground and surface water contamination can result as the soluble components, such as nitrates and chlorides, are leached into the ground and as runoff moves a variety of potential pollutants overland. Past emphasis has been upon recovery of the nutrient value of animal wastes by returning them to the land. Additional information is needed relating to the maximum quantity of waste that can be put upon the soil without causing problems. Seasonal, soil, and crop variations will influence the results.

Methods to minimize the nutrient contribution of animal waste treatment facilities need investigation. Available information is inadequate to assess the desease hazard in reuse of water from waste treatment facilities and confinement feeding operations, and from land disposal of the solid and liquid wastes. The color of the liquid fraction from confinement and treatment facilities could be detrimental to discharge and water reuse and deserves further consideration.

PART 6

WASTE TREATMENT AND DISPOSAL

Introduction

Investigations have shown that animal wastes are amenable to most processes currently used for domestic and industrial waste treatment. In discussing feasible treatment and disposal methods, it is important to realize the differences between animal wastes and municipal sewage. Sewage is water which contains some solid matter. Animal wastes are essentially solid material which contain some water. Although runoff may dilute animal wastes, the concentration of pollutants in the runoff is a number of orders of magnitude more potent than in domestic sewage (Figures 8 and 9). Animal wastes usually contain more inert material, such as feed residue and undigestible material, than does municipal sewage.

Processes used for the treatment and disposal of municipal wastes have been applied to animal wastes and usually have been unsuccessful because of a lack of understanding of the characteristics of the wastes, the magnitude of the problem, and economic constraints currently imposed by society. Hart (74) has estimated that if conventional waste treatment processes are used, a dairyman would pay about $200 per cow per year for waste treatment. Morris (19) indicated that commercial sewage treatment plants would run about $75 to $125 capital cost per pound of BOD in the livestock manure. While it is inevitable that the animal production manager, and hence the public, will have to pay for animal waste treatment and disposal, the above costs are unrealistic when applied to animal production facilities. Taiganides (75) discussed high rate digestion, using equipment and procedures employed in the digestion of sewage sludges, noted the high initial cost and potential operating problems, and forecast its lack of applicability to animal wastes.

Current interest in treatment and disposal of animal wastes centers on controlled aerobic and anaerobic biological methods and spreading of the wastes on the land. Some work has been done on incineration, dehydration, and composting of the wastes. Emphasis has been placed on processes and systems that are inexpensive and can be maintained and operated by individuals whose interest in waste treatment is minor.

Anaerobic Digestion

The high solids content and high oxygen demand of animal wastes indicate that anaerobic biological systems can be successful. Anaerobic digestion of animal wastes under controlled conditions has been successful in both laboratory and field.

Laboratory investigations with beef cattle wastes have demonstrated that loading rates from 0.1 to 0.4 pound of total solids per cubic feet per day have been successful (7). Analysis of data from that study indicated that even higher loading rates could have been feasible. Other investigations on the anaerobic digestion of beef cattle manure have demonstrated that between 8 and 9 ft^3 of gas/lb. volatile solids (VS) added can be expected from digestion systems treating these wastes (33,37). Similar studies with dairy cow and sheep manure indicated only 2.5 to 3 ft^3 of gas/lb. VS added could be expected (33). The low values that occurred with the cow and sheep manure undoubtedly were due to the fact that not all of the volatile solids in these manures were biodegradable, again demonstrating that the waste characteristics are influenced by the type of food ration and type of animal. The gas produced from digestion of animal wastes generally contains between 50 to 70% methane depending upon the environmental conditions. Carbon dioxide is the other major component of the gas.

Hart (37) digested chicken and dairy manure at rates from 0.17 to 0.31 and 0.13 to 0.22 lb. VS/ft^3/day, respectively, and concluded that both manures can be stabilized with controlled digestion. With dairy manure only about 10 to 15% of the volatile solids were destroyed. About 50% of the volatile solids in the chicken manure were destroyed.

Cassell and Anthonisen (18) digested chicken manure at a rate of 0.088 lb. VS/ft^3/day and noted that the ammonia nitrogen concentration in their digesters reached toxic levels which have been reported to be between 1200 and 2000 mg/l. They suggested that the loading be kept low to avoid the problem of toxic ammonia concentrations. The addition of sodium chloride to a digester with high ammonia nitrogen concentrations appeared to promote the digestion of chicken manure. Ammonia toxicity rarely has been a problem with municipal sewage sludge digestion but could be significant in the high rate digestion of concentrated solids with a high nitrogen content, such as animal and especially chicken wastes.

Controlled conditions were found necessary for the active digestion of duck wastes. Otherwise, the volatile acids concentration increased to the point that bacterial metabolism ceased. Continuous loading rates as high as 0.15 lb. VS/ft^3/day were successful (76).

Heated septic tanks have been advocated for the wastes from caged layer and dairy operations (77,78). A hydraulic cleaning system and unheated septic tank with effluent recycle were used for chicken waste disposal (78). The recycled effluent became concentrated and after four months averaged 0.39% nitrogen, 0.027% phosphoric acid, and 0.18% soluble potash. The effluent was disposed of on woodland areas and the sludge was returned to the soil on a batch basis.

Ludington (79) digested chicken manure, and noted the following reductions: volatile solids, 43%, total solids 33%, and total weight, 1.5%. He concluded that there was little advantage to digestion as a method of reducing the total volume or weight of material to be handled. However the biodegradable fraction was reduced.

The majority of the laboratory studies digesting animal wastes have been conducted at 35°C, a temperature unlikely to be reached in practice. Temperature affects the performance of a biological system since it affects the activity of microorganisms. Microorganisms are less active at lower temperatures and a larger number are needed to produce satisfactory results. Because sludge recycle rarely will be incorporated in animal waste digestion systems, opportunities to compensate for low temperatures by increasing the solids held in the system are few.

Field anaerobic systems can effectively handle animal waste during most of the year but can be upset during cold weather when the organisms are few and comparatively inactive (52). Low temperatures have been responsible for the failure of anaerobic units in South Dakota where the temperature on the bottom of the unit never exceeded 15°C throughout the year (80).

Laboratory units usually are well if not completely mixed, thus promoting optimum contact of the waste and the microorganisms. This condition is unlikely in field operations. The optimum quantity of mixing in any anaerobic system has yet to be adequately evaluated.

The characteristics of laboratory digestion units treating animal wastes are listed in Table 26. Although controlled anaerobic digestion can be successful, the effluent from such units generally will require further treatment before discharge to the environment.

Aerobic

Aerobic treatment of wastes is feasible when the treatment process is not limited by the rate of oxygen transfer into solution. Both laboratory and field studies have demonstrated that animal waste slurries, effluents from anaerobic systems, and runoff from confinement operations can be treated aerobically.

TABLE 26

CHARACTERISTICS OF MIXED LIQUOR--ANAEROBIC DIGESTION OF ANIMAL WASTES

Waste	Chicken Manure		Dairy Manure			Beef Cattle Manure		Hog Waste	
Loading Rate (lb. $VS/ft^3/day$)	0.173	0.305	0.122	0.215	0.18	0.08	0.16	0.15	0.17
pH	-	-	-	-	7.0	6.7	6.8	7.4	7.4
Volatile Acids (mg/l)	-	-	-	-	180	100	100	190	500
Volatile Solids (%)	-	-	-	-	84	78	80	55	71
BOD_5 (mg/l)	7600	19,000	1100	2300	-	1800	3300	-	-
BOD_5 reduction (%)	-	-	-	-	-	52	57	-	-
COD (mg/l)	31,000	70,000	36,300	13,500	-	11,700	22,000	-	-
COD reduction (%)	-	-	-	-	-	24	28	-	-
Reference	37	37	37	37	33	7	7	33	33

Jeffrey et al. (33) conducted aeration studies on hog wastes and noted that the BOD of hog manure can be reduced by 50 to 75% and 70 to 90%, respectively, in systems with detention times from 6 to 12 days. Better results were obtained with longer detention times. With continuously fed systems, loadings approaching 10 grams of dry solids per liter provided the most efficient BOD reduction while a loading of 3 grams of dry solids per liter provided the better quality effluent. One thousand cubic feet of air per cubic foot of aerator capacity per day was needed at the high loading. They also noted that criteria for aeration of domestic sewage were not directly applicable to the aeration of hog manure.

Irgens and Day (40) aerated hog waste that had accumulated beneath a slotted floor hog finishing house. They estimated that 6 cubic feet was required to dilute the waste from a 150 lb. hog to have the aerobic process feasible. About 2,500 ft^3 of air was needed per pound of BOD. Their laboratory studies indicated that the treated effluent had a BOD of 10 to 15 mg/l and contained a trace of ammonia. A detention time of 20 days was thought satisfactory.

Dale and Day (25) aerated various concentrations, from 0.5 to 4%, of dairy cattle manure and noted about a 50% reduction in volatile solids in 18 weeks. The rate of volatile solids reduction decreased as the solids concentration increased.

Loehr and Agnew (7) demonstrated that the effluent from an anaerobic unit treating beef cattle wastes could be treated aerobically. The soluble fraction from such aerobic treatment contained 100 mg/l BOD_5, 600 to 1000 mg/l COD, and 50 to 75 mg/l Kjeldahl nitrogen. The data on the soluble fraction indicated the effluent quality that could be expected if all of the solids were removed. A solids removal system would be needed in the aeration system. If the aerobic systems have a long detention time, solids sepration may not be necessary due to the low oxygen demand of the solids that would leave as part of the wasted mixed liquor.

Al-Timimi _et_ _al_. (81) investigated the effect of heat and aeration on solids accumulation in aerobic units treating chicken manure. They concluded that the percent dry matter increase over 20 weeks was 1.5% for the control, 1.33% for aeration, 1.7% for heating (96^oF), and 1.2% for aeration plug heating. Aeration was at the rate of 57 $ml/min/ft^3$ of aeration capacity.

A theoretical analysis of chicken manure (79) showed that 44 lb. of wet manure, the equivalent of 1 lb. BOD_5, would result in 8.8 lb. dry matter, 5.7 lb. volatile solids, 4.9 lb. non-biodegradable matter, 0.8 lb. biodegradable matter, 0.7 lb. synthesized bacteria and after aerobic digestion, 0.17 lb. bacterial dry matter. Even after adequate treatment of the manure to remove the oxygen demanding components, about 8.2 lb. or 93% of the original dry matter remained. A significant solids handling problem still remains after satisfactory destruction of the biodegradable material. Analyses with other animal wastes yield similar conclusions.

The past two decades have seen considerable investigation and use of aerobic oxidation ponds or lagoons for waste treatment. These units are shallow with a large surface area necessary to maintain aerobic conditions. It is generally recognized that the term aerobic does not completely describe the biochemical reactions taking place in the pond or lagoon. While ample dissolved oxygen may exist and hence aerobic biochemical reactions take place in the upper liquid portion of the lagoon, there may be little or no dissolved oxygen in the lower liquid layers. The settled solids layer on the bottom of the lagoon is devoid of oxygen and anaerobic conditions prevail. In general, however, the aerobic oxidation ponds are so designed and loaded that the facultative and anaerobic conditions have little noticeable effect on the quality of the pond effluent. The effluent normally contains considerable dissolved oxygen and may be supersaturated during daylight hours.

The traditional oxidation pond depends upon the oxygen produced by algae and the oxygen transferred to the pond by natural reaeration and wind turbulence to maintain aerobic conditions. Design criteria for these ponds range from 30 to 50 pounds of BOD per acre per day depending upon location. The high oxygen demand associated with animal wastes (Table 13) requires extremely large surface areas and volumes. For example, a confinement unit holding

1000 head of beef cattle would require an oxidation pond of at least 20 acres; a unit holding 1000 hogs would need a pond of at least 5 acres. The following surface areas have been suggested (96) as minimal for aerobic lagoons treating animal wastes: 50 dairy cows, general dairy operation--8000 sq. ft.; 1000 laying hens--8000 sq. ft.; 100 hogs--64,000 sq. ft.

Adequate land areas for traditional aerobic oxidation ponds may be available when confinement feeding is a large distance from urban areas. There is, however, a strong trend to develop confinement feeding operations near communities. Land costs increase and odors and other nuisance conditions will not be tolerated.

Aerobic systems using mechanical or diffused aeration systems have been employed to reduce the quantity of land needed for aerobic treatment. Converse et al (82) used a submerged diffused air system to aerate a lagoon, 6500 ft^3, treating hog wastes. Sedimentation units preceded the lagoon. Settled solids were removed to the fields while the overflow liquid went to the lagoon. An air rate of 35 cfm produced satisfactory results. Average values of the lagoon effluent were: BOD 60 mg/l, COD 440 mg/l, ammonia 40 mg/l, nitrates 3 mg/l, and dissolved oxygen 2.3 mg/l.

The oxidation or Pasveer ditch has attracted considerable attention as a feasible method for maintaining adequate aerobic conditions with relatively small land areas. The attraction has resulted due to the possible low cost of the process and the minimum attention that is needed. Morris (19) has estimated that oxidation ditch costs may be about one-tenth those of commercial sewage treatment plants.

Linn (83) discussed the use of the oxidation ditch for livestock manure and suggested that the minimum ditch volume needed per animal might be 7 ft^3 per hog, 50 ft^3 per head of dairy or beef cattle, and 1 ft^3 per chicken. He also estimated that for a ditch operating as a continuous unit, the daily addition of manure should not be more than 1.5% of the ditch volume. He indicated that 5 pounds of oxygen can be added to the ditch per net horsepower applied to the paddle wheel and suggested 1 foot of paddle per 400 cubic feet of ditch.

Forsyth (84) noted that 90 to 95% BOD removals were obtained with oxidation ditches. He indicated that the necessary ditch capacity per cow and hog were about 95 and 35 ft^3, respectively, and that a liquid volume of 8000 to 10,000 gallons per foot of rotor length was satisfactory. A velocity of at least one foot per second should be maintained to keep solids from settling. He reported that a semicontinuous operation in which a cycle of mixing for four hours followed by 45 minutes for settling and 15 minutes for influent addition and supernatant displacement was satisfactory. There are many modifications to the traditional oxidation ditch: continuous, semicontinuous, batch, and the use of side ditches to act as settling units.

Morris (85) indicated that there were 12 oxidation ditches treating livestock manure in the United States as of 1967. The use of oxidation ditches in the United States seemed to be mainly for odor control within the confinement housing. None of the ditches were designed to produce an effluent that could be deposited safely in surface waters. Morris described the ditches currently in use and summarized their effluent quality. BOD reductions of above 90% have been achieved. The majority of the BOD in the ditches was associated with the oxygen demand of the solids.

Solids separation can be used to produce an effluent having a BOD_5 of 10 to 20 mg/l. All mineral salts in the manure are retained in the system. The high mineral content and color of the effluent may make its discharge to a stream undesirable. Excessive foaming has been reported with a number of ditches treating livestock manures (39,41,85). Foaming may occur until adequate microbial solids are built up in the system. The foam can be controlled with antifoam agents during critical periods. If insufficient oxygen is added to the system, the ditch may foam and produce obnoxious odors. With adequate dissolved oxygen and solids there should be no foam or odors.

Data delineating the effect of temperature on the efficiency of the units, power requirements, costs involved, and desirable loading conditions are not available. Controlled field studies to obtain these are needed.

Anaerobic Lagoons

Anaerobic lagoons are units that are organically loaded such that surface reaeration and potential photosynthetic activity are unable to maintain aerobic conditions. Many lagoons currently labeled as anaerobic may be overloaded aerobic lagoons. The true anaerobic lagoon bears only a superficial resemblance to aerobic lagoons, has a different purpose, and should be designed on a different basis than aerobic lagoons.

Anaerobic lagoons offer considerable potential for handling and treating concentrated animal waste with its high solid and low water content. Anaerobic lagoons can be used as a controlled biological unit, as a holding unit prior to land disposal, to control runoff from confinement areas, or any combination thereof.

In general, the purpose of anaerobic lagoons is the removal, destruction, and stabilization of organic matter and not water purification. They can and are used as primary sedimentation units to reduce the load on subsequent treatment units. They differ from primary sedimentation units in that the settled solids are not routinely removed but are left in the unit to degrade. Solids will gradually build up, the rate depending on the solids loading rate as well as the rate of solids stabilization. Periodic solids removal will be necessary.

While held in the lagoon, the biodegradable fraction of the solids will undergo anaerobic decomposition. Considerable gas may be evolved with a resultant decrease in BOD and COD of the lagoon contents.

Anaerobic lagoons may also function as liquid or solids holding units where surge capacity is needed. They have been particularly useful for holding animal wastes prior to field spreading.

There is no need for a large surface area to promote surface reaeration and to obtain adequate light energy for photosynthesis. Anaerobic lagoons require less land area than do aerobic lagoons since they are more heavily loaded. The depth of the lagoon is not restricted by light penetration. Anaerobic lagoons should be built with a small surface area and as deep as possible consistent with construction factors and ground water conditions. The small surface area promotes anaerobic conditions and decreases the needed land area. Long liquid detention times are not required. Liquid detention times as short as three to five days have been successful (86,87).

In anaerobic lagoons, there is a relatively solids free liquid layer above a layer of settled solids. A floating scum layer usually will occur depending upon the type of waste. With a small surface area, the scum can form an effective floating cover to minimize surface reaeration and to provide some insulation for the lagoon contents during cold weather.

The actual depth of the lagoon will be restricted by the existing temperatures. The lagoon temperature may decrease with depth and may reach a point where biological reactions in the settled solids are inhibited.

The volume of the lagoon will be dictated by the organic loading rate which will be influenced by the desired frequency of solids removal. Capacity should be provided to hold the unmetabolized solids between times of solids removal.

Anaerobic lagoons are comparable to single-stage unmixed, unheated digesters. Loading values should be based on pounds per volume per time as is done for other digestion systems. Loadings of from 0.36 to 10.4 lb. VS/day/1000 ft^3 have been reported for lagoons treating a variety of wastes (30,31,32). However, the advantage of anaerobic lagoons lies with wastes that are highly concentrated and high loading rates, 132 to 320 lb. VS/day/1000 ft^3, can be used successfully (7,33,37).

Inadequacies and failures of anaerobic lagoons at a variety of laoding rates have been reported. The establishment and maintenance of conditions suitable for optimum digestion play a larger role in the success or failure of the anaerobic lagoons than does the loading rate. Alkalinity, pH, temperature, and mixing must be controlled.

Unbalanced conditions frequently occur during the start-up of an anaerobic lagoon and when environmental factors abruptly change, such as when the excess solids are removed from the lagoon or when the lagoon contents warm up in the spring. The microbial population will decrease during the winter and an adequate population of methane formers may not be present to metabolize the acids as they are generated in the spring. When excess solids are removed from an anaerobic lagoon, or when an anaerobic lagoon is being placed in operation, the population of methane bacteria may be unable to convert the acids as rapidly as they are formed. Under these conditions, it is important to control the environment in the lagoon until equilibrium becomes established.

Since digestion will not be inhibited if adequate alkalinity is present, additional alkalinity can be added to the lagoon until an optimum environment for digestion is created. Lime is commonly used for this purpose although other chemicals such as sodium bicarbonate, ammonium carbonate, and anhydrous ammonia can be used. The additional alkalinity should be mixed throughout the lagoon contents to avoid localized pH variations that may inhibit optimum biological reactions.

Temperature is one of the most important factors affecting the performance of anaerobic lagoons. Because the lagoon is built with the ground for insulation and is generally uncovered, temperature fluctuations can affect the biological system. The temperature near the bottom of one 4-foot deep lagoon in Kansas has varied from 30°C in August to 5°C in February (44). As expected, anaerobic lagoons function better in warmer climates and are less effective in colder climates.

Gas production studies in an anaerobic lagoon treating domestic wastes indicated that at liquid temperatures less than 13 to 14°C gas production was minimal (88). Maximum decomposition and gas production took place at temperatures above 19°C. Insulation of the lagoon surface will minimize temperature changes during the year. Styrofoam has been used for this purpose (89).

Anaerobic lagoons offer a possible approach for the treatment of concentrated organic wastes. The lagoons provide excellent settling capacity to intercept and separate heavy solids from the liquid flow. The effluent liquid from the lagoon can be quite potent. Table 27 summarizes the performance of a variety of anaerobic lagoons. BOD reductions in the lagoons were respectable, 60 to 90%, however; such results were obtained at warm temperatures.

The effluent from lagoons handling animal manures contains considerable organic material (Table 28). The effluent is high in oxygen demanding material, solids, and nitrogen. Most of the nitrogen in the animal wastes will be present in the effluent from subsequent treatment units since conventional treatment units remove only a small percentage of the entering nitrogen. The quality of a receiving stream may be impaired if the effluent from anaerobic lagoons is discharged without treatment. The quality of the effluent is decreased during start up operations. In practice, the quantity of liquid discharged from an anaerobic lagoon treating animal wastes could be small, the volume depending upon any runoff, the water used for cleaning of the facilities, or animal drinking.

As noted above, the solids entering an anaerobic lagoon will decompose. The rate will depend upon such environmental factors as the temperature of the lagoon, the degree of mixing

TABLE 27

PERFORMANCE OF ANAEROBIC LAGOONS

Influent Quality (mg/l BOD)	Effluent Quality (mg/l BOD)	BOD Reduction %	Reference
530	160	70	86
360	85	77	87
520	100	81	90
1100	160	85	91
15000	1500	90	89
1380	130	90	92

TABLE 28

EFFLUENT QUALITY OF ANAEROBIC LAGOONS TREATING LIVESTOCK WASTE

Livestock Waste	Swine	Poultry	Beef	Beef
Loading Rate (lb. VS/day/1000 ft^3)	0.36-3.9	4-11	85	255
pH	6.7-8.0	6.8-7.9	6.5-7.5	6.5-7.5
Total Solids (mg/l)	-	-	4780	5900
Volatile Solids (mg/l)	850-2330	-	2870	3710
Volatile Acids (mg/l)	72-528	-	120	400
Alkalinity (mg/l)	1120-2220	-	2000	1400
BOD_5 (mg/l)	-	320-1350	1340	1420
COD (mg/l)	940-3850	590-2550	4700	5500
Total Nitrogen (mg/l)	-	113-290	360	500
Reference	31	30	61	61

that takes place, and the pH and alkalinity in the lagoon. At low temperatures, the quality of the settled solids will be quite similar to those that entered the lagoon. Little decomposition will take place.

The amount of decomposition depends upon the biodegradability of the entering solids. It has been shown that a 50 to 60% reduction of volatile solids in raw domestic sludge can be expected. Studies with beef cattle manures have demonstrated a volatile solids reduction of between 40 and 55% under equilibrium conditions. Thus in an anaerobic lagoon treating similar wastes, at least 50% of the entering wastes will accumulate in the period between lagoon cleanings.

Consideration must be given to the disposal of the accumulated solids. Table 29 illustrates the characteristics of these solids as determined in laboratory studies investigating treatment of cattle wastes. Land disposal of these solids could be an acceptable method of ultimate disposal.

A design loading rate for a specific anaerobic lagoon will be determined by the rate of residual solids build-up and by the frequency of lagoon cleaning. The accumulation of material in the lagoon is closely associated with the time between lagoon cleanings. Where cleaned twice a year, a volume of 3.5 cubic feet per bird has been suggested for chicken operations (94). An anaerobic lagoon handling chicken manure contained 11.7% dry matter after 16 months use (95). The chickens were on slat floors above the lagoon.

TABLE 29

CHARACTERISTICS OF BOTTOM SOLIDS*
ANAEROBIC LAGOON UNITS (93)

Loading rate (TS/cu ft/day)	0.1	0.1	0.3	0.4
Detention time (days) (Theoretical)	10	20	10	10
BOD_5/TS	0.16	0.13	0.14	0.14
BOD_5/VS	0.20	0.16	0.18	0.18
COD/TS	1.1	1.1	0.85	0.96
COD/VS	1.4	1.4	1.1	1.3
pH	6.9	7.0	-	-
Volatile acids (mg/l)	700	800	-	-
Alkalinity (mg/l)	2340	2710	-	-
Total Kjeldahl Nitrogen (mg/l)	1720	1920	2000	2440

The gaseous by-products of anaerobic digestion were not detrimental to the chickens.

Anaerobic lagoons or ponds have been created by accident and by design, the latter generally being more successful. Niles (38) described two anaerobic ponds treating chicken wastes successfully and noted that objectionable odors were not prevalent and that active digestion occurred in the ponds.

There is a tendency to house animals on slatted floors above both anaerobic and aerobic lagoons. Several problems have been noted when anaerobic lagoons have been installed under poultry houses (97): (1) damage to the eyes of the birds, (2) off-flavor eggs, (3) production of drone flies and maggots, and (4) odors that perturb those on and adjacent to the property.

The use of anaerobic units for manure-holding prior to land disposal appears to have some favor with farmers and dairymen (56,98). Active digestion may or may not take place in these units. When the contents are agitated prior to pumping, odors do occur. The units are cleaned whenever the operators can get onto the fields.

Anaerobic-Aerobic Systems

While anaerobic systems can be effective in treating animal wastes, the effluent from such systems requires further treatment. Combination anaerobic-aerobic systems may produce an effluent which meets desired water quality standards. An anaerobic unit can serve to equalize any periodic slug loads from confinement feeding operations and can provide for partial degradation, solubilization, and gasification of organic matter. The aerobic unit can provide aerobic stabilization of the soluble and remaining particulate matter in the anaerobic unit effluent. Additional units to provide for removal of the biological solids in the effluent from the aerobic unit, for further organic removal, and for removal of nutrients may be necessary in certain cases.

Although used for domestic and industrial wastes, only recently have combination anaerobic-aerobic treatment systems been utilized for treatment of animal waste. Morris (19) reviewed the economics of treating wastes from confined livestock areas and concluded that only in exceptional cases will farm income be adequate for such treatment in traditional sewage treatment plant processes. He suggested combination systems for treating animal wastes when they cannot be distributed upon the land.

Systems combining an anaerobic lagoon, or anaerobic solids holding tank, and an aerobic unit have been investigated for treating wastes from animal confinement units (7,44,56,99). The aerobic unit can be a traditional oxidation pond or an aerated unit depending upon the land available. The above reports indicate that a combination system can provide a high quality effluent when the parameter of efficiency is percent removal. The effluent will contain oxygen demanding material, and inorganic nutrients and is not of the same quality as that produced from municipal wastewater treatment plants.

Land Disposal

The land has been the ultimate disposal point for the solid wastes of agricultural operations. Agricultural wastes, especially animal wastes, maintain and improve the soil because of the plant nutrients and organic substances they contain. Manure is one of the logical ways to build and maintain fertile soils. Significant amounts of basic plant nutrients are provided and the organic matter in livestock manure improves soil tilth, increases water holding capacity, lessens wind and water erosion, improves aeration of the soil, and has a beneficial effect on soil microorganisms. The nutrient content of animal wastes is summarized in Tables 8-11 and 13-15.

Hart (100) suggested thin spreading as a method of applying fluidized manure to land. Thicknesses of 1/25 to 1/5 inch, depending upon the season, were suggested to avoid fly breeding and to accelerate the drying. Cumulative layering of thin layers of manure is possible, reducing the land area needed. Hart indicated that less than 200 square feet per cow and 1 square foot per chicken would be sufficient for drying operations in areas where open air drying is feasible.

To avoid pollution caused by runoff, the wastes should be incorporated with the soil soon after spreading. Subsoil injection as a method of manure disposal (101) has shown definite promise. Two inches of poultry manure were deposited in the bottom of a furrow and covered immediately. The rate of disposal was estimated as about 200 tons per acre. For over three years, the wastes from 1000 chickens has been plowed into one-half acre of land with no odor offensive to neighbors (122). The maximum land application that can be handled in this manner will depend upon the type of soil, possible build-up of toxic materials in the soil, and potential ground water pollution.

Land application primarily has been used to recover the nutrient content of the wastes and to increase crop production. Land application for the purpose of disposal only has not been practiced to any large extent. Confinement feeding of animals has altered the feasibility of land disposal of such wastes. Large quantities of waste are defecated in concentrated areas and must be transported to the disposal site. It is virtually impossible to apply the waste to cropland during the growing season. The farmer usually can buy and apply chemical fertilizers more inexpensively than he can utilize free animal manure.

For the above reasons, liquid holding units and liquid disposal of the wastes on the land have promise as a method of efficiently handling animal wastes. With such holding units, the liquid can be applied to cropland while the land is fallow and when it is convenient for the farmer. Liquid manure disposal systems are being accepted by certain operators (22,23,56,102). Holding tanks with two months or more capacity have been suggested for freedom from continuous spreading (102).

Utilization of animal manures as a fertilizer or soil conditioner is no longer as economical as it has been. In 1957 the commercial fertilizer equivalent of one ton of manure could be purchased for about $2.50 (103). The expense of applying a commercial fertilizer is less than that of applying manure. On soils of good tilth, the returns from an equivalent amount of fertilizer usually will be greater than from manure.

On many farms, the value of the nutrients contained in manure does not offset the investment and labor required to give the manure the special handling necessary. Eby (104) noted that in 1966, the value of manure averaged about $4 per ton while the cost in time, labor, and equipment needed to move the manure from point of origin to point of use could run as high as $6 to $8 per ton. He suggested that land disposal represents a "least expensive method of disposal."

Riley (105) indicated that in England the value of 1000 gallons of poultry manure was about 1 pound per week per 1000 birds and that it cost 5 pounds per 1000 gallons to move the manure and dispose of it on the land. The philosophy of this article, that one might as well utilize the nutrient value of the manure since it must be moved anyhow, is typical of the thinking of many farmers.

Where wastes are liquid, land disposal by spraying (106) has been suggested. Application rates from 1/3 to 1 inch per acre have been feasible depending upon soil type. Problems inherent in spraying include the land area required, equipment, and odor production during and after spraying. The long term effect caused by spray irrigation or land disposal of material containing small amounts of toxic metals such as are in animal wastes from animal feeding has not been evaluated (107). Cumulative damage to arable and horticulture land is a possibility.

Incineration and Drying

Anaerobic and aerobic treatment can reduce the pollutional characteristics of waste solutions but reduce very little the total waste volume to be handled. Land disposal of wastes can involve significant logistic problems as well as subsequent pollution of ground and surface waters. Incineration and drying have been suggested to reduce the total volume of the wastes and to minimize water pollution problems.

Investigative work on animal wastes has been limited to poultry manure. Ludington (108) found the heat of combustion of poultry manure to be 5400 to 5800 B.T.U. per pound of dry matter. The cost of fuel needed when the manure contained 80% moisture was triple that needed when the manure contained 70% moisture. The ash would require further handling. The ash in poultry manure will run between 20-25% of the initial dry matter. Air pollution is an inherent liability of the process calling for adequate control and abatement.

There are indications that manure with a moisture content higher than 30% cannot be fed directly into the combustion chamber of an incinerator. Pre-drying, possibly using waste heat from the incinerator, would be necessary. The need for pre-drying is less acute for animal manures that are not diluted such as those from cattle feedlots and certain hog operations. Dry waste collection systems are necessary if incineration is to be used.

Ludington (108) estimated that dehydration would not be economical unless the product can be sold for at least $30 per ton since, depending upon the moisture content, the cost of dehydrating poultry manure is of that magnitude. The marketing potential of dehydrated manure is unknown. It should be noted that composting, which produces a similar product, has not been economically successful in this country due to a lack of a ready market.

Niles (38) utilized a commercial manure drier to handle the wastes and dead birds from a chicken operation of about 200,000 laying hens. The dried manure was bagged to be sold as a soil conditioner. He felt that drying was the best approach since aerobic treatment, centrifugation, sedimentation, and hydroponic agriculture were shown to be uneconomical for this operation.

Miscellaneous Processes

In addition to those noted above, various other processes have been used to handle and/or treat the waste from confinement animal operations. Because of technical or economic difficulties, these processes have not found wide application.

Wiley (109) reviewed the operation of three composting plants treating animal manure. The plant operations included windrow composting of a combined manure from 5500 steers plus the wastes from a meat packing operation, rotary drum composting of the manure from an operation handling a million chickens followed by windrow composting for completion, and rotary drum composting of the waste from one million layers. The detention time of the latter operation was six days. All plants worked well and produced suitable compost.

Livshutz (110) also used composting for poultry wastes. He suggested covering windrows with plastic, forced aeration, and recirculation of the air for efficient and economical utilization of the oxygen. An optimum moisture content of 40 to 60% was recommended.

Howes (116) investigated on-site composting of poultry manure, i.e., within the poultry house. The poultry litter was inoculated with selected microorganisms to aerobically decompose the resulting manure. He reported that the process was relatively inexpensive, provided an odorless and fly-free environment, and kept dust to a minimum.

A suitable market must be available before composting can be attractive as a method of waste treatment and disposal. While composting may be feasible for isolated animal production units, it is doubtful that it is suitable for the volume of animal wastes generated throughout the country. Without a market, virtually all of the original dry matter remains for further disposal.

Cassell and Anthonisen (18) evaluated vacuum filtration as a method of reducing the volume of poultry manure. Ferric chloride, ferric chloride and lime, and nonionic and cationic polyelectrolytes were ineffective. Anionic polyelectrolytes effectively dewatered chicken manure. The specific resistance was reduced by as much as a factor of 15 and filter cakes as high as 25% total solids were produced. Polyelectrolyte dosages of 1.9 to 3.6% of the initial total solids content were required. A ton of manure containing 10% solids would require a maximum of 7.2 pounds of polyelectrolyte. No data were presented on the quality of the filtrate or on possibilities of its disposal or treatment.

Dewatering of farm slurries from dairy cattle housing using drying beds has been explored (43). Measurements of specific resistance to filtration showed that these slurries would drain more slowly than most sewage sludges. Only a small amount of water was removed by drainage. Evaporation of that remaining would take an excessive length of time. The initial rate of drainage was markedly increased by conditioning with aluminum chlorohydrate. The filtrate, however, contained nearly 2% suspended solids.

Lime and chlorine have been used to suppress odors in hog wastes and to provide some degree of treatment (111). The wastes were collected from beneath self-cleaning slotted floors where anaerobic conditions had created objectionable gases and odors. Lime treatment reduced the BOD of the effluent by about 50%, possibly by precipitation of organic matter. About 0.15 pound of lime per 100-pound hog per day was required to maintain the pH at 10.0. Over a six-months period this amounted to $0.62 per hog. The chlorine demand of the wastes was about 0.1 pound active chlorine per 100-pound hog per day or about $6.40 per hog for a six-months period. About half this concentration would suppress odors.

Irgens and Day (40) noted that chlorination of diluted swine waste eliminated some of the odor and improved flocculation and dewatering. The COD of chlorinated and filtered waste was reduced about 72%.

Treated effluent that will satisfy BOD and solids requirements will still contain excessive bacterial concentrations. Chlorination may be necessary prior to discharge to receiving waters. Gates (76) investigated lagoons for use at duck farms and noted that the chlorine needed to reduce the coliform density in the effluents to 2300 per 100 ml or less ranged from 0.85 to 4.6 pounds per 1000 ducks per day. Subsequent studies indicated that 24 pounds of chlorine per 1000 ducks per day was needed to reduce the coliform count to less than 100 per 100 ml in a 30 minute contact period or about 1.32 cents per duck over a seven week growing period (116). The economics of chlorination became more favorable, 0.3 to 0.4 cent per duck over the growing period, when biological treatment of the duck wastes was satisfactory.

Dilute wastes, such as waste waters from farms, are amenable to conventional treatment processes. Quiescent settlement of cow and dairy shed washings for one hour reduced the BOD and suspended solids content by 11 and 55% respectively (112). Cattleshed washings can be partially purified with chemical coagulants but such treatment increases the ultimate volume of the solids. Painter (71) reported that the addition of 500 mg/l aluminum sulfate followed by sedimentation for one hour reduced the BOD and suspended solid content of cattleshed washings by 30 and 76%, respectively.

Trickling filters have been successful in certain cases. Painter (71) indicated that when coagulated cattleshed wastes were applied to laboratory filters, effluents contained 20 mg/l BOD. Dilution and recirculation of filter effluent were necessary for successful treatment without coagulation. The influent BOD was about 570 mg/l. Field trickling filter experiments at lower temperatures, variable application rates, and lesser initial dilution were less successful. In these cases the effluent BOD, after settling, ranged from 40 to 140 mg/l.

Wheatland and Borne (113) used trickling filters to treat settled farm wastewaters in a field installation. Loading rates ranged from 0.08 to 0.14 lb. BOD/yd^3/day, and the filter influent contained from 680 to 1390 mg/l BOD_5 and 100 to 224 mg/l suspended solids. The settled filter effluent contained from 12 to 50 mg/l BOD_5, 8 to 155 mg/l suspended solids, and usually was well nitrified. Ponding was infrequent.

Bridgham and Clayton (115) treated dairy manure with trickling filters preceded by sedimentation tanks. Loadings ranged from 6 to 22 pounds of BOD per 1000 ft^3 of filter volume. Effluent BOD concentrations ranged from 80 to 750 mg/l and varied with temperature and loading. Scum and sludge were not removed from sedimentation unit which became overloaded and released solids to the trickling filter.

The waste entering the sedimentation unit was 2 pounds of manure mixed with one gallon of tap water and added daily to the sedimentation unit. This concentration purportedly simulated the concentration of flushings from many dairy operations.

Animal wastes contain considerable energy and nutritive value. The gross energy value of chicken feces ranged from 3.22 to 4.48 calories per gram of dry matter and the nitrogen content from 0.03 to 0.07 gram of nitrogen per gram of dry matter depending upon the feed ration (117). The utilization of dried chicken manure as part of the feed for chickens and ruminants has been suggested (117-121). Bull and Reid (117) concluded that chicken manure could be fed to dairy cattle if dried to 80% dry matter or more. The milk produced from cattle on such feed was normal.

Beef animals and sheep can utilize broiler litter as part of their feed (119). The rate of gain and carcass grade were not significantly different for beef steers fed 25% broiler litter. The taste of the meat was unaffected. In another study, sheep and steers readily consumed a combination of cattle feedlot manure and hay (120). It was concluded that combining such material offers the cattle feeder a challenging opportunity to improve feed efficiency and at the same time reduce the cost of removing manure from feeding pens. A third study (121) found that concentrated cattle manure could be successfully fed to pullets and laying hens. Egg production was affected only slightly. Catfish were also found to make rapid gains on feedlot manure if care was taken to prevent oxygen depletion.

European Practice

Allred (122) recently visited Northern Europe and reported on current animal waste disposal practices there. The following statements are taken from the report of his visit. Problems in Europe have become acute due to public awareness of the effects of water pollution and the necessity for farmers to reduce labor costs through mechanization. Legislation in every country prohibits the dumping of any waste materials within a watershed where they will contribute to the pollution of surface or ground water supplies.

Several approaches to the handling and disposal of livestock manure were in use. The most common was the distribution and use of manure on farm land as an aid to soil fertility, tilth, and structure. Partial reduction by anaerobic digestion, with residues applied to the soil, has been attempted on a limited scale with divergent degrees of success. Attempts are made to aerobically oxidize and stabilize animal wastes, primarily in oxidation ditches, to a degree that the sludge residue can be disposed of on the soil and the liquid effluent to receiving streams. Methods employing drying, bagging, and marketing of the dried material as a fertilizer are being attempted. No plants attempting complete incineration of farm manure were observed.

The farmer and research worker in northern Europe place greater importance on the use of manure for soil building purposes than do their counterparts in the United States. In Europe, greater research effort is being directed toward methods of handling and hauling manure to the field rather than the design and construction of major treatment facilities at each farm.

The manure cellar system, commonly found in Norway, was perhaps the least costly and most simple system of manure handling noted. Animals are housed on the first floor level of a barn and manure wastes are dropped through slatted floors or open manholes into the basement manure cellar. The cellars are made sufficiently large to accommodate several weeks storage. At intervals depending on weather and field soil conditions, the manure is removed from the cellars and distributed on the fields. The cellar system has advantages for hilly terrain but was less prevalent in areas of flatter terrain. Ventilation of the animal area was necessary to avoid asphyxiation of the animals by gas generated during the manure storage.

Underground manure holding tanks, located outside of, but adjacent to, the animals, also were common. Adequate storage capacity was essential.

Allred (122) noted that most farmers expressed the desire for larger holding tanks than they presently had. Because of increased mechanization usually associated with the installation of slurry or liquid manure type facilities, farmers often increased their herd size after the system was placed in operation with a concurrent increase in the frequency of emptying the holding tanks.

The holding tank was the most costly part of most manure disposal systems. The increased initial cost of a larger tank was often justified by a saving in labor and the ability to permit the farmer to empty the tank less frequently and at more opportune times.

Both sprinkler irrigation systems and tank wagons were used to transport the manure slurry to and distribute it on the fields. Nozzles that permitted large solids to pass were advantageous.

Chicken and cow manures were dehydrated and marketed as fertilizers in the Netherlands, Sweden, and Germany. Only fresh manure and manure relatively free from sand and other inorganic materials were used. The packaged product had a moisture content of less than 10% and sold for about $50 per ton. Allred noted that manure dehydration companies appeared to be facing difficult price competition because of the availability of relatively inexpensive commercial fertilizers.

Apparently, anaerobic digestion of animal wastes was utilized as a source of methane gas during and following World War II. This practice became uneconomical when fossil fuels again became available. Controlled anaerobic digestion of animal wastes was not practiced at the time of Allred's visit.

The traditional oxidation pond or aerobic lagoon had not met with success in Northern Europe due to the limited land area available and the relatively cool temperatures. Considerable interest has been generated in the oxidation ditch for treatment of animal wastes. The ditches occupy a smaller land area and employ mechanical aeration for mixing and transfer of oxygen. Hog and dairy wastes were stabilized in oxidation ditches. Individuals working with the oxidation ditch as a method of treatment and reduction of farm wastes were optimistic about its future possibilities.

Allred (122) presented no information on the number of animals per farm or production unit, on loading conditions for various treatment facilities, on surface and ground water pollution that may have occurred, or on cost of treatment processes and operations.

Morris (85) also has reported on European practices of animal waste disposal. He noted the interest in controlled aerobic methods of treating animal wastes especially in oxidation ditches.

Information describing European conditions in regard to animal production and number of animals per confinement unit is scarce. The available information suggests that animal concentrations in the United States, i.e., on the order of 1000 or more beef cattle, 1000 or more hogs, and 10,000 or more chickens per confinement unit are not matched in Europe. In fact Allred (122) noted that in some European countries, the governments have established various types of subsidy-incentive programs to encourage the retention of small "family-size" farms. Disposal of farm manures is usually not as serious a problem in areas where livestock are widely dispersed on many small farms.

European experience in the area of animal waste disposal can serve as a guide for practice in the United States. However, the availability of land, the trend toward large confinement units and small numbers of production units, and even different temperature and weather conditions in the areas of animal production in the United States indicate that American animal waste disposal practices will be more diverse than European practices. Processes that may be unsatisfactory in other parts of the world may be suitable in the United States.

Summary

Considerable information is being accumulated by a number of investigators on a variety of treatment processes applicable to animal wastes. To date, each investigation has been done on a relatively small scale by one or two researchers working on a particular project. Agricultural engineers of today do not have a grasp of the fundamentals of waste treatment processes. They frequently conduct research that has little chance of success and use treatment processes under conditions that obviously lead to disastrous results.

Sanitary engineers have little if any knowledge of animal management practices, of the use of land as a disposal site for wastes, of the economics of animal production, and of the impact of waste treatment practices on the animal production industry.

Coordinated, interdisciplinary activities involving sanitary engineers, agricultural engineers, economists, agronomists, those interested in animal husbandry, and others interested in the problem are seriously needed. These activities should center around field as well as laboratory research and demonstration projects. Funds should be made available so that all data pertinent to a particular project can be collected and evaluated. For example, a waste treatment project should collect data not only on the usual parameters such as BOD, solids, and bacteria but on conservative substances such as nitrogen, phosphorus, chlorides, potentially toxic metals, antibiotics, and so forth. Land disposal projects should collect data not only on crop response but also on the effect of potential pollution caused by rainfall and runoff, on travel of soluble components through the ground, and on the maximum quantity of wastes that can be applied to the land. The effect of various waste management practices should also be evaluated within each project.

Training is seriously needed to bridge the gaps, and to merge disciplines that must be involved in solutions to the problem. However, training activities should not be the source of the major research activity in this area.

Many treatment systems are in use. Few have been evaluated closely to obtain pertinent loading, performance, and quality data. Animal wastes are different in quality and quantity from domestic and other industrial wastes. Adoption of processes used for municipal and industrial wastewater treatment are not likely to be successful with animal wastes unless process modifications are made for differences in waste characteristics.

Because of the quality of animal wastes, anaerobic processes will be a part of many feasible systems treating animal wastes. Information is needed on the quality of effluent from these systems, loading conditions, the effect that seasonal temperature variations will have on performance and efficiency, and the need for and effect of various mixing rates.

Anaerobic processes may be controlled and used as manure holding facilities or controlled to accomplish optimum organic decomposition as well. In either case, anaerobic processes by themselves will not be sufficient. Subsequent treatment will be necessary. Aerobic treatment processes can be used. Additional data are needed on the quality of the effluent from the aerobic processes, the effect of shock loading conditions occasioned by slug loading of preliminary anaerobic units, the effect of temperature variations, and above all the cost of operating and maintaining such systems.

The entire problem of the ultimate disposal of solids remains untouched. Land application of waste liquids and solids has been used for centuries but few data have been accumulated on the optimum amounts of material that can be placed on the land, on proper management techniques, on land disposal of wastes with different qualities, on subsequent pollution that may occur, and on changes in soil conditions that may result. Major emphasis to date has been on crop response which, while valuable, provides little information on disposal techniques.

Land disposal is becoming less economical due to the large quantity of wastes generated, the costs of transporting the wastes to suitable disposal sites, and the availability of inexpensive chemical fertilizers. Land disposal may continue to be a "least expensive" way of ultimate solids disposal but alternative ultimate disposal methods need to be evaluated. Incineration has been only slightly investigated. Wet oxidation could be another possibility in areas where concentrations of solids are large. Low temperature wet oxidation can produce soluble organic components that may be incorporated into animal feed. Sanitary land fill is another possibility for dry and semisolid wastes. Biological reactions within such a fill and possible ground water pollution need to be evaluated.

Feasible and economical water renovation processes need to be evaluated not only to assure adequate water quality in receiving streams but also to supply water for reuse on farms and in confinement operations. Nutrients, chlorides, color, and trace metals may prevent treated water from being reused for the above purposes. The low volumes of water and the high concentrations of contaminents that are in treated water will challenge those that attempt to obtain suitable processes.

At present, there is no profitable method of livestock manure utilization and it is unlikely that one will be developed. Animal waste handling, treatment, and disposal will cost something. This must be made clear to those that produce the animals and the public that consumes them. The cost of satisfactory waste treatment will be related to the desires of the public to minimize pollution from these sources, to the willingness of the consumer to accept higher meat prices to pay for the treatment, and to the ingenuity of those in all professional disciplines in developing suitable treatment systems.

No one treatment process or treatment system will be the solution for all animal production units. A variety of management and treatment systems will have to be developed. Obviously these systems must be consistent with American practice, needs, and economies. Mass adoption of European practice will not be adequate. Such practices, however, can be a guide for potentially successful American systems.

PART 7

COSTS

Introduction

The increase in confinement feeding of animals, noted in Part 3 of this report, has been spurred by a decreasing profit margin per animal. The economics of pollution and nuisance control are an important factor in the design and operation of confinement units and may mean the difference between financial success and failure for the owner. Stubblefield (123) described the difficulties encountered in Arizona as the larger cities expanded and became neighbors of or encompassed cattle feedlots. He noted that, while feedlot relocation was a possibility, the feeders would lose over 50% of their capital investment if they did so.

Two general types of costs are pertinent to the solution of the animal waste problem: (a) the cost of animal production and the profit available for waste treatment and disposal facilities and (b) the cost of constructing, operating, and maintaining adequate treatment and disposal facilities.

Animal Production Costs and Profits

It has been reported (124) that the initial investments in buildings and equipment for confinement units are in the range of \$3 to \$6 per hen, \$20 to \$40 per hog, and \$1,000 to \$1,500 per dairy cow. Within the cattle production industry, production has been cyclic (Figures 4,5), but the long term production trend has always been up. Experience has indicated that, approximately one year out of ten, cattle feeders do not obtain enough from the sale of their cattle to pay for their feed. Recent information from the Department of Agriculture noted that the average midwestern cattle feeder fell 42 cents short of covering his production costs in buying, feeding, and fattening a cow for the consumer slaughter market during the first half of 1967 (139). Overhead costs, pasture costs, and death losses were not included.

Feed can amount to 70% to 80% of the total cost of producing slaughter cattle. Feed costs increase with the age and size of the animal and the length of the feeding period. Table 30 illustrates the financial return available to cattle feeders in recent years. The data on the short-fed cattle are typical of what can be expected of cattle feedlot operations. Although the short-fed cattle appear to produce somewhat less profit, such is not the case, because the turnover of such cattle is rapid. At least two and frequently three lots of short-fed cattle can be fed in the same feedlot per year. Feeders in Arizona and California have had to develop more efficient feeding methods because of high grain and roughage costs to compete with feeders in the grain country.

The income to the producers from animal production since 1940 is illustrated in Figures 10 and 11. Although prices have stabilized fairly well in the 1960's, the over-all trend has been a decreasing unit income from chickens and hogs. With increasing labor and equipment costs, constant and especially decreasing unit costs mean that those in the animal production business are caught in a cost squeeze. The result has been mechanization of the

TABLE 30

CATTLE FEEDING SYSTEMS--1951-1963

System	Range Returns Above Cost of Feed & Cattle
Long Fed*	
Steer calves	$85 to - $11
Heifer calves	79 to - 18
Yearling steers	81 to - 13
Short Fed**	
Common-medium yearlings	80 to - 30
Choice yearling steers	62 to - 42
Heavy steers	66 to - 47

*Usually on farm more than 240 days.
**Usually on farm less than 240 days.

industry and increased confinement feeding of animals. The income from milk production has been constant for many years, undoubtedly due to price supports and governmental buying of milk. The cost squeeze in the dairy business has resulted in a decrease in the number of dairy farms and dairy cattle in the United States (See Figure 2).

Studies on commercial cattle feedlot operations (126) indicated that feedlots of 2,000 head or larger operating at or near capacity may enjoy critically significant cost advantages over smaller volume operations. Further studies (127) indicated that costs may be lowered in cattle feedlot operations by increasing capacity to 5,000 head. Additional economies in buying, transporting, and selling might be gained in larger operations. Capital requirements for a 5,000 head operation would be relatively large, over $1 million for feed, feeders, and feedlot services. Typical costs of cattle feeding operations in several states are presented in Table 31. Small

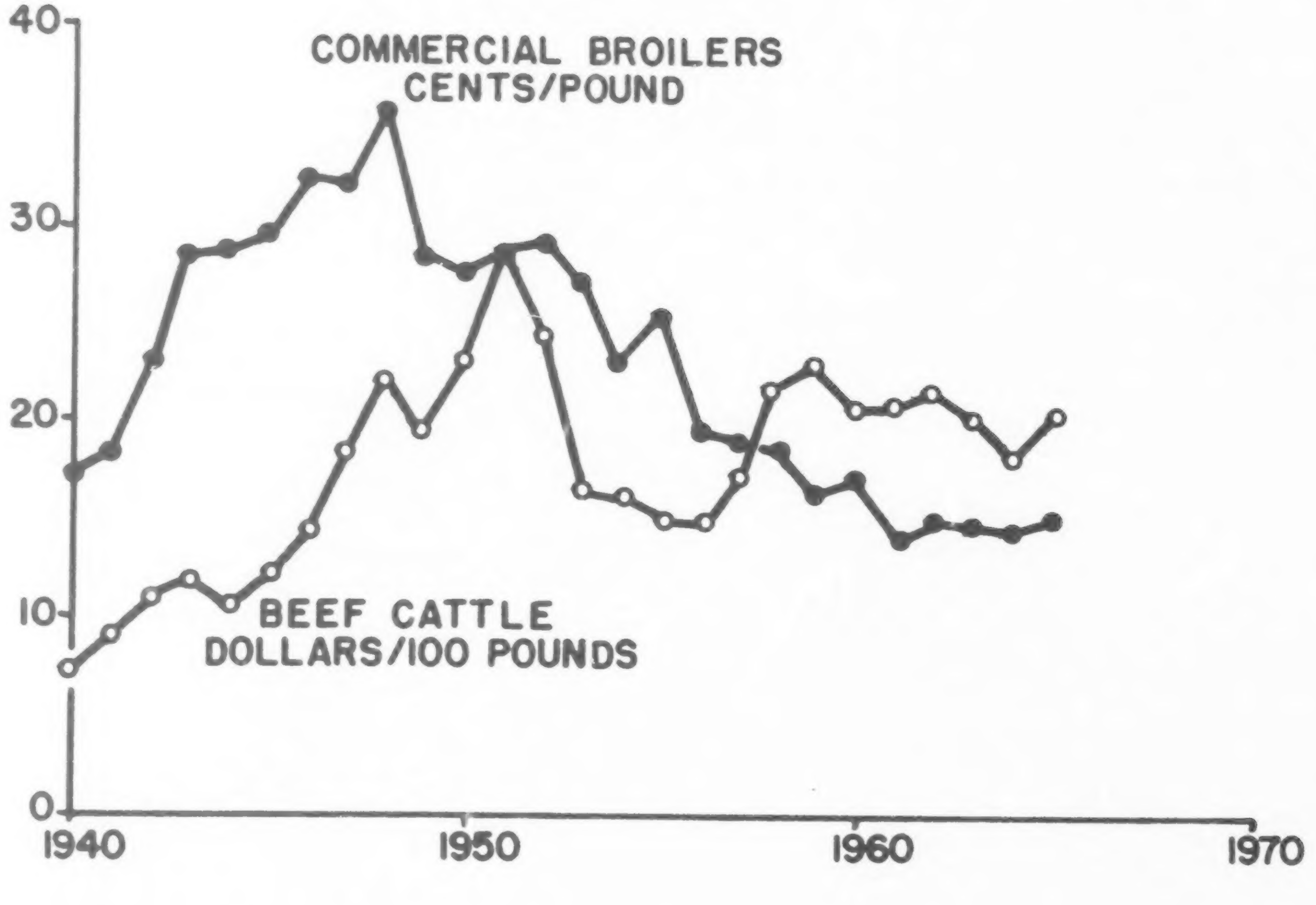


FIGURE 10

INCOME FROM BROILER AND CATTLE PRODUCTION
IN THE UNITED STATES (1940-1965)(3)

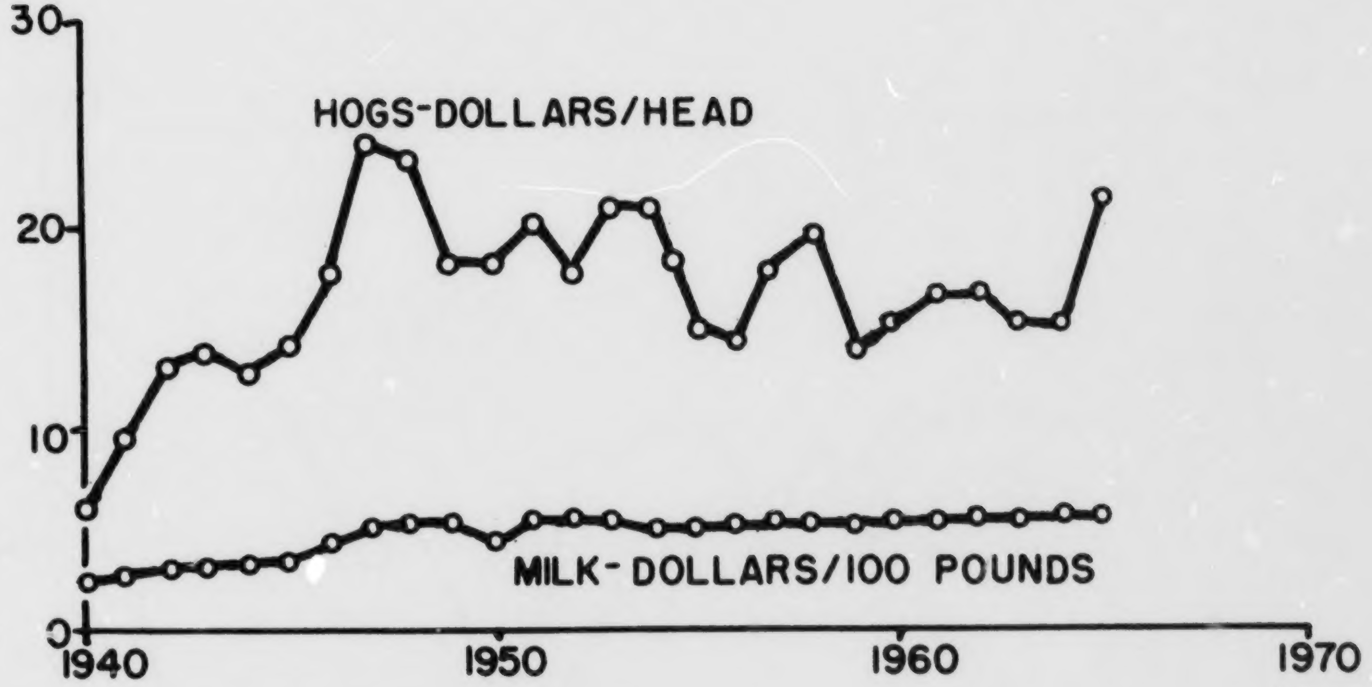


FIGURE 11

INCOME FROM HOG AND DAIRY OPERATIONS
IN THE UNITED STATES (1940-1965) (3)

TABLE 31

COST OF CATTLE FEEDING OPERATIONS
(CENTS/HEAD/DAY) (127)

State	Feedlot Capacity (number of head)						
	100	500	1000	2500	5000	7500	10,000
Illinois	13.4	-	-	-	-	-	-
California	-	-	-	14.2	11.2	9.2	9.3
Oklahoma	-	14.5	12.1	11.5	10.6	10.4	10.2

feedlots have a relatively high unit cost. Prices for 180-day feedlot service in Iowa and Nebraska were $25.76 per head in 1965 and $30.18 per head in 1966 (126). Between 15.3 and 16.8 cents per head per day were sufficient to cover all costs on feedlot operations.

Data on the difference between selling and purchase price for various types of cattle are shown in Table 32. The investment and animal costs of feedlots of various sizes feeding short fed yearling steers on pasture and drylot (Table 33) further demonstrate the economics of confinement operations and of mechanization. Investment and annual costs decrease as the feedlot size increases and increase with increased mechanization. Although the numbers will vary, similar comparisons exist for the other types of cattle feeding systems noted in Table 32. Short fed yearling and common steers are on feed approximately 180 days and are the type usually found in beef cattle confinement feeding operations.

TABLE 32

AVERAGE PRICE MARGIN (DOLLARS) (128)

Cattle Feeding Systems	1952-1962
Long Fed Steer Calves	-0.49
Long Fed Heifer Calves	1.20
Long Fed Yearling Calves	1.56
Short Fed Yearling Steers	2.10
Short Fed Common to Medium Steers	4.32
Light Yearling Steers on Pasture and Drylot	1.71

TABLE 33

INVESTMENT AND ANNUAL COST FOR SHORT FED YEARLING STEERS* (128)

Feedlot Capacity (number of head)	Investment per Head (Dollars)		Annual Cost per Head (Dollars)	
	Limited Mechanization	High Mechanization	Limited Mechanization	High Mechanization
20	249		27.60	
40	199		21.70	
60	170		18.40	
80	162	229	17.50	25.60
100	155	203	16.75	22.60
120	151		16.20	
200		166		18.20
500		147		16.00
1000		124		13.90

*Investment and annual cost in feed storage, buildings and equipment, cattle fed hay, corn, and protein supplement.

Stubblefield (123) reported that the profits from commercial feeding of cattle can be respectable. He indicated that a net profit of $5 per animal fed per lot turnover is possible. This is the equivalent of $10 to $15 per head of lot capacity since two, and sometimes three, lots of short-fed cattle can be fed in the same feedlot per year.

Data on investment and annual costs for hog, chicken, and broiler operations could not be located. Cost relationships in these operations probably are similar in nature but not necessarily in magnitude to those in the cattle industry

Animal Waste Treatment Costs

A minimum of data is available to permit accurate estimates of the cost of various treatment facilities for animal wastes. Kesler (129) evaluated the cost of hauling and spreading, lagooning, and combined lagooning, hauling, and spreading for various size confinement hog operations. Costs of equipment, labor, construction, and of fertilizer nutrients in the manure were included. His results are presented in Table 34 Hauling and spreading was the lowest net cost of disposing of hog manure when cropland was available and the manure was used to replace commercial fertilizers. The combination of lagooning, hauling, and spreading was the second lowest net cost. Total lagooning was the highest net cost since no nutrients were recovered and no credit applied This study assumes that the farmer will pay close attention to the nutrient balance for his crops and will not apply excess inorganic nutrients in addition to those in the manure. The economics of scale on the waste disposal techniques evaluated are apparent.

TABLE 34

ECONOMIC EVALUATION OF LIQUID MANURE DISPOSAL FROM CONFINED HOG OPERATIONS (129)

	Hauling and Spreading			Lagooning			Hauling, Spreading and Lagooning		
Number of Hogs produced annually	500	1500	2500	500	1500	2500	500	1500	2500
Annual Cost (dollars)									
per hog	0.69	0.37	0.30	0.32	0.28	0.28	0.79	0.43	0.36
per 1000 gallons	3.82	2.05	1.69	1.78	1.56	1.54	4.37	2.39	2.02
Return above total disposal costs* (dollars)	-58	305	670	-160	-421	-695	-107	213	521

*The value of the replacement costs of the salvaged manure is included as a credit to the operator in all but the lagooning operation.

Morris (19) reviewed the economics of liquid manure disposal from confined livestock. He noted that the scale and efficiency of the operation and prevention of dilution of the manure determine if the manure can be spread on the fields at a cost equal to or less than the value of nutrients used by the crop.

Liquid handling of manure followed by land disposal has been accepted by confinement feeders because of the flexibility of the method and because of the ability to recover nutrients in the wastes. Costs of liquid holding and pumping systems have ranged from \$35 to \$52 per head of dairy cattle at a variety of dairy farms (102). Mixing of the contents of the holding tank was done only during the pumping.

Sobel and Guest (26) reported costs of about \$40 per head of dairy cattle with adequate storage capacity and from \$77 to \$133 per cow capacity for a commercial liquid system with waste storage of one month.

Wolf (23) noted that sprinkler systems used for hog manure disposal in England cost about \$0.66 to sprinkle 1000 gallons of liquid manure compared with \$3.70 with a tank wagon spreader. Labor, depreciation, and operating costs were included in these values.

Power costs for oxidation ditches treating animal wastes have been reported to be about 90 kw.-hr. per dairy cow and 72 kw.-hr. per pig (84), 36.5 kw.-hr. per pig (40), and 40 kw.-hr. per hog, and 328 kw.-hr. per dairy cow (83). These figures are per animal finished per year. The operating costs per year have been estimated as 10% to 15% of the total cost of the ditch (39). Morris (19) indicated that about 1095 kw.-hr. would be required per dairy cow per year which would amount to about $1.50 per ton of manure. He noted that the oxidation ditch did not seem to be a lower cost method of manure disposal unless the cost of labor associated with alternative methods was high, about $2 per hour.

Costs of dehydration of animal manure have been estimated at $25 to $35 per ton of poultry manure (108). The costs depend upon the moisture content, decreasing with decreasing moisture content.

Livshutz (110) has indicated that the cost of composting poultry manure using a plastic covering and forced aeration could be between $25,000 and $50,000 for a farm handling 100,000 chickens.

Treatment Process Cost Comparison

More data are available on construction and operational cost of facilities treating municipal wastes. Although these costs are not directly applicable to animal wastes they can be used, together with the above data, to provide gross estimates of the costs of treating animal wastes by various processes. On the following pages, estimates have been made of the land area, process size, and, where available, costs of waste treatment processes for the following confinement feeding operations: beef cattle--1,000 and 10,000 head, dairy cattle--100 head, hogs--1,000 head, chickens--10,000 and 100,000 animals. Since waste production will vary with the size of the animal, the following animal sizes have been assumed;

dairy and beef cattle--1,000 pounds, hogs--100 pounds, chickens--5 pounds. The assumed sizes of the confinement operations and of the animals are typical in this country.

As observed from Part 4, data on characteristics of animal wastes vary considerably due to a wide variety of factors. Table 35 summarizes the range of values reported in the literature and the values that have been used for estimating treatment unit size and costs in this part of the report. The values selected are educated estimates of average values that appear to be realistic. Liquid flow data for beef cattle feedlots are nonexistent. Intermittent runoff would cause the only significant flow from the feedlots in use at present (1967).

The treatment processes selected for evaluation in this comparison have been selected because of their applicability to animal wastes. These processes are: oxidation ponds, aerated units, anaerobic lagoons, anaerobic digestion, incineration, composting, wet oxidation, and land disposal. A combined anaerobic-aerobic system has also been included.

Oxidation ponds--Traditional oxidation ponds are designed at between 20 and 40 lb. BOD_5/acre/day with a detention time of 30 to 90 days. The ponds are 4 to 5 feet deep for proper development of photosynthetic action and wind mixing. Assuming a loading rate of 30 lb. BOD_5/acre/day, the sizes of the ponds to treat the wastes from the assumed animal feeding operations have been calculated (Table 36). Because of the low liquid flows, the average detention times are in the order of years. An additional source

TABLE 35

SUMMARY OF ANIMAL WASTE CHARACTERISTICS*

	Dairy Cattle	Beef Cattle	Hogs	Chickens
Liquid flow from confinement operations (gallons/animal/day)				
Range	5-30	-	1.6-6	0.05-.2
Value used in Part 7	10	-	5	.1
Manure Production (pounds/animal/day)				
Wet Solids				
Range	38-86	60-65	2.8-9.5	0.11-.39
Value used in Part 7	70	60	5	0.25
Dry Solids				
Range	6.8-14	3.6-10	0.5-1.6	0.05-.10
Value used in Part 7	10	10	0.9	0.06
BOD_5 (pounds/animal/day)				
Range	0.94-1.53	1.02	0.20-.56	0.006-.032
Value used in Part 7	1.0	1.0	0.30	0.015

*Data from Part 4

TABLE 36

SIZE OF POSSIBLE TREATMENT UNITS--
OXIDATION POND AND OXIDATION DITCH

	Dairy Cattle 100 head	Beef Cattle 1000 head	Beef Cattle 10,000 head	Hogs 1000 head	Chickens 10^4 birds	Chickens 10^5 birds
Oxidation Pond						
Surface area (acres)	3.3	33	330	10	5	50
Volume* (10^6 gallons)	5.4	54	540	16	8.2	82
Detention time (days)	7100	-	-	3200	8200	8200
Oxidation Ditch						
Minimum Ditch volume (ft^3/animal)**	50	50	50	7	1	1
Ditch volume (ft^3)	5000	50,000	500,000	7000	10,000	100,000
Detention time (days)	37	-	-	75	375	375
Surface area (acres)	0.029	0.29	2.9	0.04	0.057	0.57
Oxygen Demand (lb./day)	200	2000	20,000	600	300	3000
Horsepower Required	5	40	400	12	6	60
Length of Rotor required (ft)	2.8	28	280	8.5	4.2	42

*Pond 5 feet deep **Data from Part 6

of water would be needed to fill the ponds due to the low influent waste flows. The small inflow could cause difficulties in maintaining a proper water depth and balance. This problem would arise whenever the net outflow, including seepage and evaporation, was larger than the net input of rainfall over the pond surface by more than the waste inflow. This critical difference would be about 3.1 in./yr, 6.7 in./yr and 2.7 in./yr for oxidation ponds treating the waste from dairy, hog, and chicken operations respectively. These numbers are equivalent to the waste inflows to the ponds. The bottoms of oxidation ponds are sealed to prevent ground water pollution and to maintain proper water levels. Some seepage does occur. The amount permitted by various Departments of Health range from 0.1 to 0.25 in./day (36 to 90 in./yr). The waste inflow from the assumed confinement operations would not be adequate to overcome permitted seepage losses. An additional source of water would be needed to maintain proper water depth.

The ponds would be nonoverflowing. This has distinct advantages for pollution control. The large land area needed and the need for make-up water can be disadvantages.

The design of oxidation ponds for treatment of animal wastes is controlled by the BOD loading and not the hydraulic loading, assuming adequate water depth is maintained. Many oxidation ponds have been successful at BOD loading rates considerably in excess of 30 lb./acre/day (130,131) especially where temperatures are warm and considerable sunlight and wind prevail. In areas where loadings higher than those assumed in this report can be maintained, the size and cost of the oxidation ponds, and the quantity of needed makeup water would be decreased.

It is difficult to utilize the costs of oxidation ponds treating municipal waste to estimate the cost of ponds treating animal wastes. Hydraulic and BOD loading conditions control the design of ponds treating municipal wastes while only BOD loading controls ponds treating animal wastes. Land costs vary throughout the country but are likely to be low in areas where the confined animal feeding operations are located.

Aerated Unit--In an aerated unit oxygenation is accomplished by mechanical or diffused aeration and by induced surface aeration. The turbulence level maintained in the unit insures adequate distribution of oxygen but is usually inadequate to maintain solids in suspension throughout the unit. Because sunlight is unimportant, aerated units can be deeper than oxidation ponds. The mechanical or diffused aeration permits units that are considerably smaller than equivalent oxidation ponds. Land costs decrease but operational costs are greater due to the need for power to supply the necessary oxygen.

The oxidation ditch is the most common type of aerated unit used for the treatment of animal wastes. Minimum ditch volumes, surface areas, oxygen demand, and other factors relating to oxidation ditches treating the wastes from the assumed animal production units are tabulated in Table 36. The following assumptions were made:

depth, 4 feet; two pounds of oxygen needed per pound of BOD applied; 50 pounds of oxygen per horsepower per day; and three pounds of oxygen per hour per foot of rotor. The actual horsepower, oxygen transfer, and length of rotor requirements are related to the depth of submersion and rotor speed.

Anaerobic Lagoons--Anaerobic lagoons are a possible method of handling and treating concentrated animal wastes with their high solid and low water content. Attention must be given to the environmental conditions affecting the biological reactions in the lagoon if it is to be operated as a controlled biological process.

As noted in Part 4, anaerobic lagoons can be loaded at high rates. Loadings from 0.4 to 320 lb. VS/day/1000 ft^3 have been successful with animal wastes. A design loading rate for a specific anaerobic lagoon will be determined by the rate of solids build-up in the lagoon and the desired frequency of lagoon cleaning. A trade-off between size and cleaning will exist. A larger lagoon will require more land area but less cleaning, and a smaller lagoon just the opposite. Two loading rates, 50 and 200 lb. VS/day/1000 ft^3, have been used to estimate relative sizes of anaerobic lagoons for the confinement animal feeding operations previously assumed (Table 37). The depth of all lagoons has been assumed at 10 feet. The animal wastes have been assumed to contain 80% volatile material.

Seepage and evaporation could be less than the waste inflow, under the assumed conditions, and the anaerobic lagoons would have

TABLE 37

SIZE OF POSSIBLE TREATMENT UNITS--ANAEROBIC LAGOON AND COMBINED ANAEROBIC-AEROBIC SYSTEM

	Dairy Cattle	Beef Cattle		Hogs	Chickens	
	100 head	1000 head	10,000 head	1000 head	10^4 birds	10^5 birds
Anaerobic Lagoon						
Loading - 200 lb. VS/1000 ft^3/day						
Volume (ft^3)	4,000	40,000	400,000	3,600	2,400	24,000
Surface area (acres)	0.009	0.09	0.9	0.008	0.005	0.055
Detention time (days)	30	-	-	5	18	18
Loading - 50 lb. VS/1000 ft^3/day						
Volume (ft^3)	16,000	160,000	1,600,000	14,400	9,600	96,000
Surface Area (acres)	0.037	0.37	0.37	0.033	0.022	0.22
Detention time (days)	120	-	-	22	72	72
Combined Anaerobic-Aerobic System						
Anaerobic Unit - 50 lb. VS/1000 ft^3/day						
Volume (ft^3)	16,000	160,000	1,600,000	14,400	9,600	96,000
Surface Area (acres)	0.037	0.37	3.7	0.033	0.022	0.22
Oxidation Pond						
Surface Area (acres)	1.6	16.5	165	5	2.5	25
Oxidation Ditch						
Surface Area (acres)	0.014	0.14	1.4	0.021	0.029	0.29

an overflow. As noted earlier, such overflow will have a high oxygen demand, and contain organic material, aquatic nutrients, and esthetically undesirable items such as color and chlorides. Anaerobic lagoons are likely to be used as part of a treatment system rather than the sole treatment unit.

Combined Anaerobic-Aerobic System--Since the effluent from an anaerobic unit can be potent, a combined anaerobic-aerobic system will be necessary if the liquid effluent is discharged to a receiving stream. A conservative estimate of the performance of an anaerobic lagoon would be that, under the worst of conditions, i.e., cold temperatures, little microbial activity, it will act as a sedimentation unit. Under more favorable conditions, i.e., controlled environmental conditions, both sedimentation and biological degradation will take place.

It was assumed that approximately 50% BOD reduction would take place in the anaerobic lagoon preceding the aerobic unit. The size of the resulting aerobic unit, an oxidation pond or oxidation ditch, and the size of the over-all system are shown in Table 37.

Anaerobic Digestion--Controlled anaerobic systems are another possibility because of the characteristics of animal wastes. Data on mixed and heated anaerobic digestion systems treating solids from municipal and industrial solids indicate that loadings of 0.2 lb. VS/ft^3/day and above are quite feasible.

While high-rate anaerobic digestion has the advantages of comparatively small volumes and a usable end product, methane, certain costs are involved. These include those of mixing and heating as well as the cost of the physical plant and the cost of digested sludge disposal facilities. Data at the Chicago municipal treatment plants (132) indicated that annual costs of digesting municipal sludge varied from $32 to $14 per ton of sludge fed to the digesters as the feed solids varied from 2 to 8%. Animal waste can be fed to high rate digesters at 10% or more solids. It is not unreasonable to estimate the costs of high-rate digestion for animal wastes at about $10 per ton of dry solids. The size and cost of units for the solids produced in the assumed animal confinement operations are shown in Table 38. The above costs represent the annual cost, that is, the capital recovery, maintenance and operational costs, of sludge solids digestion facilities. The initial cost of constructing the digestion facilities has not been determined.

Incineration--Biological treatment can reduce the pollutional characteristics of animal wastes but does little to reduce the volume to be handled. Incineration can reduce the volume. The residual volume, the ash, may be 20 to 25% of the original total solids and perhaps 3 to 4% of the wet animal waste.

Animal wastes can be collected in a relatively dry state, 80 to 85% moisture. There is a certain logic to handling these wastes as a solid rather than diluting them with water and handling them as a liquid slurry. When water is added for dilution, both the water and original solids must receive treatment.

TABLE 38

SIZE OF POSSIBLE TREATMENT UNITS--HIGH RATE ANAEROBIC DIGESTION AND WET OXIDATION

	Dairy Cattle	Beef Cattle		Hogs	Chickens	
	100 head	1000 head	10,000 head	1000 head	10^4 birds	10^5 birds
High Rate Anaerobic Digestion (.20 lb. VS/ft^3/day)						
Volume (ft^3)	4,000	40,000	400,000	3,600	2,400	2,400
Annual cost						
per year per animal	$1,820	$18,200	$182,000	$1,650	$1,100	$11,000
capacity per year	$18.2	$18.2	$18.2	$1.65	$0.11	$0.11
Wet Oxidation						
High Pressure						
Construction cost						
per unit	$25,000	$250,000	$1,500,000	$22,500	$15,000	$150,000
Annual cost						
per day	$5	$50	$500	$4.5	$3	$30
Low Pressure						
Annual cost						
per day	$1.50	$15	$150	$1.35	$0.90	$9

While few data are available on the cost of incinerating animal wastes, cost data are available for the incineration of municipal solid wastes (133). Most incinerators for municipal solid wastes cost from $3,000 to $4,000 per ton of rated 24 hour capacity to build and equip.

Operating costs have ranged from $2 to $6 per ton of refuse processed. The cost of incineration of sewage solids has been given as $30 per ton of dry solids (134). The large quantity of wastes generated from large animal confinement operations suggests that incineration might be feasible. The construction and operating costs for an incinerator to handle the solids from the assumed animal confinement operations are listed in Table 39. The costs that were assumed were: construction, $3,000 per ton of 24 hour capacity; operating costs, $5 per ton of waste processed.

Adequate air pollution control and abatement equipment will be needed. The cost of such equipment will be in addition to the costs estimated in Table 39.

Composting--Composting offers the possibility of retaining the nutrients contained in the animal wastes for subsequent use on the soil. Previous enthusiasm for composting in the United States has been due largely to the possibility of producing a saleable and possibly profitable product. Evidence and experience in this country indicate that, except in special cases, composting should be thought of as a treatment process and not as a profit making operation.

TABLE 39

SIZE OF POSSIBLE TREATMENT UNITS--INCINERATION, COMPOSTING, AND LAND DISPOSAL

	Dairy Cattle	Beef Cattle		Hogs	Chickens	
	100 head	1000 head	10,000 head	1000 head	10^4 birds	10^5 birds
Incineration						
Construction cost	$1,500	$15,000	$150,000	$1,350	$900	$9,000
Annual Costs						
per day	$2.50	$25	$250	$2.25	$1.50	$15
per animal capacity per year	$9.20	$9.20	$9.20	$0.83	$0.55	$0.55
Composting -	Estimates are the same as for incineration					
Land Disposal						
Thin spreading Area (acres)	0.46	4.6	46	0.46	0.23	2.3
Sub-soil Injection 100 tons wet solids/acre Area (acres)	0.035	0.3	3	0.02	0.013	0.13
10 tons wet solids/acre Area (acres)	0.35	3	30	0.2	0.13	1.3
Spraying (.05"/acre) Area (acres)	7.3	-	-	3.7	7.3	73

Capital costs are relatively high. Costs will approximate those of an incineration plant for a comparable amount of refuse disposed. Capital costs may range from $1,000 to $6,000 per ton of capacity with plant operating costs varying from $2 to $5 per ton of solids received at the plant (133). When nonsaleable, the compost will require further disposal. The costs of incineration operations have been used to estimate those of composting (Table 39).

Wet Oxidation--Wet air oxidation is a process in which the organic matter is heated with air to an initiating reaction temperature, usually between 300° and 400° F. The mixture then enters a reactor where the desired oxidation takes place. The degree of oxidation depends on the temperature, pressure, holding time, and concentration of the sludge entering the process. Operating pressures may be from 100 to over 3,000 psi depending upon the degree of oxidation desired. When the solids content of the entering organic matter is over 4 to 6%, the process may be thermally self-sufficient. The process has been used for the treatment of municipal and industrial waste solids.

High pressure wet oxidation can be rather complete, providing up to 90% COD reduction. The remaining liquid, containing perhaps 6,500 mg/l soluble BOD and 1000 mg/l total nitrogen requires further disposal. Construction costs have been estimated at about $50,000 per ton of dry solids per day for small plants having a capacity of about 5 tons per day and $25,000 per ton for plants with capacities of 100 tons per day. Operating costs ranged from $6 to $15 per ton of dry sludge solids processed (135). An average cost of $10 per ton was used to estimate the animal costs for high pressure wet oxidation noted in Table 36.

Low pressure batch type plants might be better suited for use with wastes from animal confinement operations. The effluent from a low pressure plant would contain soluble organic compounds and partially oxidized sludge that might be reused in the feed ration of the animals in confinement, the nonbiodegradable compounds such as lignin, being oxidized to a more biodegradable form. Construction costs would be somewhat less than those of the high pressure system. Operating costs for low pressure sludge oxidation systems have ranged from $2 to $4 per ton of dry solids processed (136). A cost of $3/ton was used in the estimates noted in Table 38. Advantages accruing from the low pressure system would be due to simpler operation, less operating personnel needed, and possible reuse of the system effluent as a portion of the animal feed.

Estimated costs of wet oxidation systems are presented in Table 38 for the animal confinement units that have been assumed in this report.

Land Disposal--As noted in Part 6, wastes can be disposed of on the land in a variety of ways; thin spreading, subsoil injection, and spraying. Optimum application rates and associated costs are not available. Comparative land areas needed for these three methods are indicated in Table 39.

Hart (100) suggested a rate of 200 ft^2 per cow and 1 ft^2 per chicken for drying of their manures on the land. On a dry solids basis, a hog produces about one-tenth that produced by cattle (Table 35). The land area need for thin drying of hog manure was estimated at 20 ft^2 per hog or one-tenth that for a cow.

Only two articles describing subsoil injection of animal wastes appear in the literature. One (101) indicates a rate of 200 tons of wet solids per acre may be possible. The other (122) indicates that a lower rate, 0.25 ton per acre was successful. Two rates, 10 and 100 tons per acre, were used for the estimates (Table 35).

Spraying of the waste is a possibility. Rates from 1/3 to 1 inch per acre have been successful with dilute animal wastes (106). The flow values indicated in Table 35 were used to estimate the needed land area. Animal manures in the volumes noted would not be dilute and a lower application rate, 0.05 inch per acre, was also used to estimate the land area needed. Additional acreage will be needed since the land will have to be rested periodically to absorb the sprayed wastes. Spraying cycles of once every three to four days have been found beneficial in certain areas.

Evaluation of Compared Processes

Considerable liberty has been taken in developing the size and cost relationships presented in Tables 36-39. The waste production values per animal, and the design criteria used were selected by the author based upon his experience and his estimation that the values and criteria were possible and realistic. It should be stressed that the relationships shown in Tables 36-39 should not be used as if they were actual design sizes and costs. The relationships are based upon quite arbitrary values. In many cases, perhaps only one or two pieces of data were available for evaluation and estimation. In other cases, data obtained for the treatment, handling, and disposal of nonanimal wastes were used to estimate relationships for animal wastes.

The processes selected for treatment and disposal of animal wastes are not all-inclusive nor have all factors inherent in a specific process been included. Processes such as sanitary landfill, dehydration, incorporation of animal wastes as feed for other animals, pyrolysis, and others yet to be developed may be more suitable. With the exception of an anaerobic-aerobic system, each process has been evaluated as if it were the sole process. This will not happen in actual practice. Ultimate solids disposal must be accomplished with every process whether it be biological such as anaerobic digestion or physical such as incineration. Many alternative systems are possible, such as lagoons followed by separate land disposal of the liquid and the solids and incineration followed by land disposal of the ash.

Factors not incorporated in the size and cost estimations include: (a) handling and transportation from the confinement operations to the site of treatment or disposal, this can be a significant cost due to the quantity of waste involved, (b) pollution abatement and control equipment and procedures such as air pollution control when handling dry solids; nuisance control, e.g., odors and noise; and land use control to prevent subsequent ground and surface water pollution if land disposal is practiced; (c) further treatment of the liquid portion of certain processes such as possible tertiary processes following aerobic treatment, and processes to treat the liquid resulting from wet scurbbing devices for air pollution control; (d) manpower involved to oversee, maintain, and operate suitable facilities, and (e) ultimate solids disposal from most of the processes.

Even if a suitable system is available for the treatment of the waste from animal confinement operations, consideration also should be given to control of runoff when animals are housed in the open. The runoff contaminates receiving waters and should be controlled. A system for handling this liquid will be necessary but has not been evaluated in this report.

While the information in Tables 36-39 cannot be used in a definite sense, it can be used to shed light on processes that appear to have unexplored potential for animal waste treatment and to indicate where additional work would be valuable. The size (Table 40) and costs (Table 41) of possible treatment and disposal processes have been compared.

Comparisons were made on the basis of surface area for those processes requiring relatively large land areas but comparatively little operation, maintenance, and construction costs and on the basis of annual cost for those processes requiring small land area

TABLE 40

SIZE OF POSSIBLE TREATMENT UNITS--SUMMARY COMPARISON*

	Dairy Cattle	Beef Cattle	Hogs	Chickens
Surface Area(acres)				
Oxidation Pond	33	33	10	0.5
Oxidation Ditch	0.29	0.29	0.04	0.0057
Anaerobic Lagoon				
200 lb. VS/1000 ft^2/day	0.09	0.09	0.008	0.0005
50 lb. VS/1000 ft^2/day	0.37	0.37	0.033	0.0022
Combined System - Total Area				
Anaerobic Lagoon plus Oxidation Pond	16.9	16.9	5.03	0.252
Anaerobic Lagoon plus Oxidation Ditch	0.51	0.51	0.053	0.0051
Land Disposal				
Thin Spreading	4.6	4.6	0.46	0.023
Sub-soil Injection				
100 tons/acre	0.35	0.30	0.02	0.0013
10 tons/acre	3.5	3.0	0.2	0.013
Spraying				
.05"/acre	7.3	-	3.7	0.73

*Based on 1000 animal per type of confinement unit and arbitrary assumptions made in Part 7 of the report.

TABLE 41

COST OF POSSIBLE TREATMENT UNITS-SUMMARY COMPARISON*

Animal Cost (dollars per year)	Dairy Cattle	Beef Cattle	Hogs	Chickens
High Rate Anaerobic Digestion (0.2 lb. VS/ft^3/day)	$18,200	$18,200	$1,650	$110
Wet Oxidation				
High Pressure	$18,200	$18,200	$1,650	$110
Low Pressure	$ 5,500	$ 5,500	$ 660	$ 44
Incineration	$9,100	$ 9,100	$ 825	$ 55
Composting	$9,100	$9,100	$825	$ 55

*Based on 1000 animals per type of confinement unit and arbitrary assumptions made in Part 7 of the report.

but comparatively large construction and operational costs. Although some data on construction costs for a few processes are included in Tables 38 and 39, sufficient information was not available to compare construction costs for all processes evaluated.

On a comparative basis of 1,000 animals per confinement unit, it is obvious that the treatment and disposal of cattle wastes will be more expensive and require more land area than will the treatment and disposal of wastes from other animals. This was to be expected because of the quantity of waste excreted from each animal (Table 35). However, confinement chicken operations frequently house from 100,000 to 1,000,000 birds. Treatment and disposal costs for units of such size will be comparable to smaller confinement units feeding larger animals. Beef cattle feedlots are reaching capacities of 10,000 and more head. Considerable construction and annual costs as well as land area will be involved for suitable treatment and disposal from such operations. Unit costs per animal or per animal capacity of confinement area will be in relation to the quantity of wastes defecated per animal (Table 35) and to the processes used (Tables 40-41).

Experience with other wastes indicates that oxidation ponds can cost the least. The large land areas needed for this process are obvious (Table 40). Supplemental water will be necessary to maintain a proper water balance in the pond. Where suitable land is not available, other methods of waste treatment are necessary. Mechanical aeration, such as accomplished by the oxidation ditch can reduce the needed land area drastically (Table 40). Large power demands will be necessary for the aeration equipment (Table 36) and will prove a significant expense.

An anaerobic lagoon will reduce the load and hence size of subsequent aerobic units. Disposal of residual solids, probably on the land, will be necessary.

Although the land area needed for subsoil injection of wastes was estimated from fragmentary information, this method appears to have potential as an ultimate disposal method if the rate is greater than 10 tons per acre. Not only are smaller land areas necessary than for thin spreading and spraying but subsoil injection appears to be a complete disposal method and one that will cause little secondary pollution of surface waters. Pollution of ground waters is possible. Subsoil injection has the greatest potential when the wastes are not diluted excessively.

High rate anaerobic digestion and high pressure wet oxidation appear to cost more than low pressure wet oxidation, incineration, and composting. It is unlikely that complex processes, such as high rate anaerobic digestion and high pressure wet oxidation, processes that require large capital and annual costs as well as suitable operating personnel, will be feasible for animal confinement operations at the present time.

Another insight into the costs of solids disposal can be obtained from the estimated costs of activated sludge disposal at the Chicago Sanitary District (Table 42). Disposal of the solids on the land is the least cost solution.

TABLE 42

COSTS FOR DISPOSAL OF ACTIVATED SLUDGE (CHICAGO SANITARY DISTRICT) (140)

	$/dry ton
Drying and sales as fertilizer	$60
Zimmerman process	50
Dewatering and incineration	57
Digestion and permanent lagoon	50
Digestion and reclamation of farm land	15
Digestion and reclamation of strip mines	16

Summary

There is a significant lack of usable data for evaluating the economics of animal confinement units and of treatment and disposal facilities for such units. The income from animal production operations has either decreased or stayed the same in recent years although the general cost of living continually has increased. This squeeze in costs has caused an increasing trend toward confinement feeding operations. This trend will increase in the future. The corporation type animal production operation will occur with the larger animals as it has occurred with the egg and broiler production industry. Confinement feeding operations emphasize and accelerate the need for satisfactory waste treatment and disposal.

Size and costs for a number of treatment processes were explored. There is no single process that is satisfactory. Combinations of processes will be necessary to meet the needs of specific operations and locations. Consideration must be given to the effect of animal management and waste handling systems on the waste treatment and disposal system. Since the wastes originate as semisolid material, it may be better to handle and dispose of the wastes as a semisolid rather than increase the volume to be handled and process it as a liquid slurry. Some farmers have shown a preference for handling the waste as a slurry, however,.

Both liquid and solid disposal methods appear to be needed. From the size and cost standpoint, simple anaerobic units, mechanical or diffused aeration systems, simplified incineration units, low pressure wet oxidation, and sub-soil injection of wastes should be explored as potential processes for animal waste treatment and disposal. The author believes these processes should be given high priorities for research and field demonstration investigative studies.

There is an almost complete lack of cost information relating to animal waste treatment processes. It is imperative that all research studies collect and report information that can be used to estimate the cost of the various processes. Laboratory studies will be necessary to delineate feasible processes. Field studies on as large a scale as possible should follow as quickly as possible to determine the performance of the processes when exposed to the vagaries of environmental conditions and waste management practices. All such projects should include the collection of detailed cost as well as performance data so that the process can be adequately evaluated.

As more and better design and cost information becomes available, the estimates presented in Tables 40 and 41 can be re-evaluated to be more realistic.

PART 8

LEGAL

Federal

The Congress of the United States has been developing a Federal water pollution control program since the turn of the century, but with increasing effect and rapidity since 1948. The basic policy and philosophy of water pollution control in this country can be found in the Water Pollution Control Act of 1948 and subsequent legislation enacted in 1956, 1961, 1965, and 1966. The basic policy includes the following: (1) Congress has the authority to exercise control of pollution in the waterways of the nation, (2) both health and welfare are benefited by the prevention and control of water pollution, (3) Congress has no intent of divesting either the states or the Federal government of authority to prevent or control water pollution, and (4) a national policy for the prevention, control, and abatement of water pollution shall be established (137).

The legislation covers all forms of pollution irrespective of its source. Certain types of pollution have been classified as "natural" or "background" pollution. "Natural" pollution can come from a number of sources such as runoff from urban, rural, and forest lands, natural chloride seeps, decaying vegetation such as leaves and crop residue, and animals on pasture and grazing lands. Such pollution is difficult to control because of its diverse nature, lack of controllable point sources, and inadequate knowledge concerning feasible collection and treatment techniques. Also it has been assumed that this type of pollution not only is uncontrollable but is of small significance compared to municipal and industrial wastewaters.

Recent developments in animal production techniques have altered the traditional concept of including pollution from animal wastes as "background" or uncontrollable pollution. About one-half of the wastes from livestock remain on pasture and uncultivated land. The wastes from the remainder accumulate in pens, feedlots, and loafing areas. Increased automation and efficiency of crop use are expected to increase the latter fraction. Animal wastes can cause serious pollution as has been noted in Part 5 of this report.

The Federal Government has the authority to control and abate the pollution caused by animal wastes. This authority should be exercised as needed. Farmers and ranchers should recognize that drainage from feedlots, farmsteads, and fields is clearly pollutional if such drainage contributes material objectionable to the water use of others. The fact that agriculture can cause pollution must be recognized and acknowledged by the agricultural community.

State

Kansas is one of the first States in the country adopting regulations for the control of water pollutants from animal feedlot operations. The regulations stipulate that, effective July 1, 1967, the operator of any newly proposed confined feeding operation of 300 or more animals or an operation using waste ponds or lagoons must register with the Kansas State Department of Health prior to construction and operation of the facilities. The operator of any existing confined feeding operation having 300 or more animals must register by January 1, 1968. If in the judgment of the Department a proposed or existing confined feeding operation does not constitute a water pollution problem, provision of water pollution control facilities will not be required. If such a confined feeding operation does constitute a water pollution potential or if water pollution occurs as a result of the operation, the operator shall provide water pollution control facilities constructed in accordance with plans and specifications approved by the Department. A permit is required for water pollution control facilities and is granted subject to continual and satisfactory operation of the pollution control facilities.

The minimum water pollution control facilities for confined feeding of cattle, swine, and sheep are stated as retention ponds capable of containing three inches of surface runoff from the confined feeding area and all other waste contributing areas. Each confined feeding operation will be reviewed and evaluated on its own merits.

Construction of runoff retention ponds will greatly relieve surface water pollution during and following rains. Laboratory and field studies have indicated that the effluent from such ponds may not meet the requirements for discharge into a receiving stream. Subsequent treatment of the pond effluent or other forms of waste treatment may be necessary to protect the water resources of an area.

Modifications of the Kansas regulations are being considered in other livestock producing States. Such regulations are a needed step in the right direction and will need to be altered as additional economically feasible treatment procedures become known and available.

Local

In addition to State and Federal pollution control programs, public health nuisances of confined feeding operations can be abated at the local level by either city or county governments. As an example, Kansas statutes indicate that regulations providing minimum standards for location, construction, and operation of such facilities can be promulgated by cities and are applicable within five miles of the corporate limits.

It is unlikely that local legislation will be very effective. Many feeding operations are more than five miles from any city. Other feeding operations are adjacent to small cities that will hesitate to enforce legislation that may move a thriving enterprise from their area. Control and abatement programs on the state and Federal levels will be more successful.

Great Britain

A variety of legislation relevant to river pollution in Great Britain has been enacted over the centuries (138). The Public Health Acts of 1937, 1951, and 1961 are the most pertinent to the problem of agricultural wastes. The 1937 Act regulated the admission of trade effluents to sewers and exempted those discharges made prior to the Act. The 1951 Act defined the term "trade effluent" to exclude domestic sewage and any liquid discharged from any land or premises, wholly or mainly used (whether for profit or not) for agricultural or horticultural purposes and from scientific research or experimental areas.

Under such definitive type of legislation, agricultural wastes were excluded from governmental control. The Public Health Act of 1961 removed the exemption on pre-1937 discharges and enabled local authorities to levy charges and impose conditions of discharge on them. Certain effluents excluded by the Act of 1951 from the definition of trade effluents were included. As a result of the 1961 Act, farm effluents are now regarded as trade effluents and their reception into a sewer may now be subject to conditions imposed by the local authorities, even though they may have been so discharged for a long time.

June 1, 1963 was the day upon which the discharge of farm effluent into any watercourses became illegal in England. The effluent from farms must either be retained on the farm or cleaned to a standard considered satisfactory by a river board. The legislation has had a significant effect in reducing pollution from farm effluents. Some farmers have ceased to discharge effluents and have made arrangements to dispose of their waste on the land. Others are separating uncontaminated surface and roof water and are spreading only wastewater on land. A few farmers have installed treatment plants.

Summary

Animal wastes and farm effluents have polluted surface and ground waters. The increasing trend toward confined animal feeding will magnify these problems. Authority for the abatement and control of pollution from agricultural sources exists within the Federal government although it has not been used in a specific case. States are awakening to the need to provide adequate regulations concerning the disposal of animal wastes. The efforts of both Federal and state authorities should be increased.

It will be necessary to supplement and parallel any regulatory and enforcement activity with a planned educational program and a productive research program. The educational program is needed to alert the public and the agricultural community to the need for adequate treatment and disposal of all agricultural wastes. The research program is needed to develop and demonstrate economically feasible treatment and disposal methods that can be used with animal wastes.

The achievement in England, accomplished by better regulatory control and by continuing education and research, can be duplicated and exceeded in the United States. The problem of agricultural wastes requires acknowledgment by the public coupled with an aggressive and enthusiastic regulatory and research program.

PART 9

SUMMARY AND RECOMMENDATIONS

Summary

Agriculture is the biggest producer of wastes in the United States. Animal wastes constitute one of six sources of farm wastes whose management and disposal have become one of the most challenging problems of modern farming. Three pounds of manure are defecated for every quart of milk produced. Six to 25 pounds of manure are produced per pound of weight gain for livestock. While some of this is left in pasture and rangeland, about one-half of it is desposited in feedlots, barns, and other animal production units from whence it must be removed for disposal. The future will see a greater increase in confinement feeding of animals with an increasing need for better waste treatment and disposal procedures.

Although disposal of animal wastes has been a nuisance to the animal producer, only recently has it been recognized as a potential national problem. Within the last few years agricultural experiment stations and Federal agencies such as the Departments of Agriculture, Interior, and Health, Education, and Welfare have begun to support research in farm wastes management.

The animal waste problem results from problems in treating and disposing of animal wastes, in their management, or both. There is little current information to assist in solving these problems. That which is available is scattered in diverse publications and not in a form that is readily useful to the farmer or animal producer.

Few efforts have been made to coordinate all or even most of the pertinent factors having an impact on the solution within a particular study. Suitable solutions to the animal waste problems require identification and analysis of the properties of the wastes, handling procedures, treatment techniques, utilization methods, and ultimate disposal. There is a significant need for an integrated interdisciplinary approach that involves all the above factors. The approach should be initiated and developed by the professionals in the appropriate disciplines and not primarily by the apprentices or the graduate students.

Confinement production of livestock and poultry results in large volumes of accumulated animal excreta and associated feed, water, and bedding or litter. Concentrated animal wastes are potential sources of undesirable pollution to ground and surface waters until they are incorporated with the soil. A number of cases of serious surface and ground water pollution have been documented. Pollution of ground water within a localized area is highly probable whenever accumulations of animal wastes are stored on or below the ground unless stored in water tight structures. Rural runoff water must be considered as a factor in water pollution control problems because sizable organic and inorganic loads are discharged to the receiving stream over short periods of time.

Historically, most animal wastes have been recycled through the soil with a minimum of direct release to receiving waters. This is not possible in as many instances as it once was due to the trend toward confined animal production operations. The animal producer finds himself with large volumes of wastes that have low value and physical and/or economic restrictions which limit the feasibility of recycling animal wastes through the soil environment.

There are no simple solutions to the problem. Past failures have occurred because of a lack of understanding of the waste characteristics, a lack of understanding concerning suitable treatment, disposal, and management methods, a lack of appreciation in many areas that a problem existed, and a general feeling that treatment, disposal, and management methods should produce a profit or cost very little. Emphasis has been on cheapness rather than adequacy of method.

The principal approaches that should be taken are a program of research to determine economically and technologically feasible methods of animal waste treatment and disposal and a program of education of the public and the waste producer on the need for solutions to the problem of animal wastes. A comprehensive program of integrated waste management is necessary. Solutions will come when coordinated systems are developed that will obtain the desired level of sanitation and the public is convinced of the necessity of paying for it.

In these days, there is no longer any way an individual sector of society can dispose of wastes by simple export. Ultimate disposal of most of the stabilized material will have to be on agricultural lands. Treated waste material will not be able to compete with commercial fertilizers. Encouraging the farmer to use the treated wastes may require that it be given to him at a cost below the actual cost of stabilizing it.

Agriculture has differed from other industries. In some areas the profit margin has been maintained at what was considered a reasonable level. Large-scale increases in production costs can only be met by another form of subsidy or by increasing the cost of the product to the consumer directly.

The public must understand that waste disposal, including that from animals, is worth whatever it costs within the framework of sound administration and engineering. The cost is part of the price that must be paid for our high standard of living.

Recommendations

Additional summary material has been presented in each part of this report. The following recommendations result from both the body of the report and the summaries. It should be noted that the recommendations are not presented in any order of priority. A flow sheet itemizing these recommendations (Figure 12) concludes this Part.

(1) The population increase in the nation and the increase in per capita consumption of meat will cause greater numbers of animals, especially cattle and broiler chickens, to be raised. Livestock feeding operations will increase throughout the nation both in number of units and the number of animals per unit. The

problems associated with the handling, treatment, and disposal of wastes from these units will be magnified in the future.

It is recommended that objectives be set with regard to acceptable degrees of treatment and disposal to control the problems that will result from indiscriminate discard of animal wastes into the environment. Adequate education, research, development, and training concerning these problems and their solutions should be given high priority.

(2) Pollution caused by wastes from animal production facilities can be as detrimental to the environment as wastes from any other industry. Many animal production facilities have been developed with little planning and concern for the nuisance and pollutional characteristics inherent in the facilities.

It is recommended that future research and educational activities dealing with animal wastes develop and emphasize the interrelationships of animal handling and production operations and waste management operations, such as waste handling, treatment, and disposal operations, to eliminate pollution from animal production facilities.

(3) Research activities on animal waste management to date (1967), have been closely allied with training activities and have resulted from master or doctoral research.

It is recommended that future training activities be separated from research activities. Training activities should not be the source of the major research activity in animal waste control and abatement.

(4) Educational and training activities are vital to a successful attack on the animal waste problem. Activities should not only be geared to the education and training of professional people capable of attacking the problem but they should be geared also to educating the general public and the agricultural community that there is a problem, the magnitude of the problem, and the costs of its solution.

Formal training takes a relatively long time to produce qualified professional people capable of attacking a problem. A reservoir of competent sanitary engineers, agricultural engineers, economists, agronomists, and other professionals trained in various aspects of agriculture and waste management exists in this country. Other than their own specialties, few of these individuals have the knowledge that is needed to understand and solve the complexities of animal waste control and abatement.

It is recommended that educational and training activities aimed at the control and abatement of animal waste pollution include: (1) formal training and education to produce professional people capable of solving the problem, (2) education of the general public and the agricultural community to the magnitude and costs of the problem, (3) opportunities such as senior fellowships at qualified educational institutions and in governmental organizations to broaden the background, training, and experience of professionals competent in only one aspect of animal waste control and abatement, and (4) workshops at all levels to disseminate information concerning the problem and proper techniques for its solution.

(5) There is a wide divergence of data on the characteristics of animal wastes. This divergence results from differences in housing and management practices, in types of ration fed, from the analytical techniques employed, and from waste handling and collection techniques Probably no single study of animal waste characteristics would be as valuable as information obtained from a number of independent investigations conducted under widely varying conditions

It would be valuable to have a detailed study of the applicability of the traditional physical, chemical, and biological analytical techniques to animal wastes since these techniques were developed primarily for liquid wastes. Modification of current analytical techniques may be desirable and necessary.

It is recommended that all projects conducting research on animal waste control and abatement collect data on the characteristics of the wastes used in the project. Information concerning housing and management practices, rations fed, and waste handling and collection practices used in the project also should be reported.

It is recommended that a detailed study be initiated to delineate the proper analytical techniques to be used with animal wastes. Proper techniques for accurate determination of waste characteristics, performance of treatment facilities, and quality of resultant effluents are needed.

(6) Many treatment systems are possible. Few have been evaluated closely to obtain pertinent loading, performance, effluent quality, and cost data. Information is needed on the effect of

seasonal temperature variations and loading conditions. Both solid and liquid handling, treatment, and disposal systems are feasible and should be investigated. No one treatment process or system will be the solution for all animal production units. A variety of management and treatment systems will have to be developed.

It is recommended that coordinated, interdisciplinary research activities be initiated to: (a) investigate all possible animal waste treatment processes, (b) develop new processes for waste handling, treatment, and disposal, (c) provide information on processes for both solid and liquid handling and treatment of the wastes, (d) determine how these processes interact with animal production operations, (e) provide detailed data on the quality of the solid, liquid, and gaseous material, if any, that result from these processes, (f) itemize the construction, maintenance, and personnel costs associated with the processes, (g) investigate better control of the wastes at the source, i.e., the animal, and (h) delineate possible treatment systems that may be used to meet the control and abatement objectives of a region and/or the nation.

(7) Conventional physical, chemical, and biological treatment processes can effectively remove over 90% of the solids and oxygen demanding material in the untreated animal wastes. Effluents from such processes still may not be suitable for discharge to streams, not only because of remaining solids and oxygen demanding material but also because of detrimental nitrogen, phosphorus, chloride, and trace metal concentrations. The color of the effluent may also be a problem.

It is recommended that research be conducted on the effluents of processes used to treat animal wastes to: (a) determine possible detrimental concentrations of material such as nitrogen, phosphorus, chlorides, color, and other factors that could prevent the effluents from being discharged or reused, (b) develop suitable tertiary processes and systems to allow the effluents to be discharged or reused, and (c) determine the possible effect of secondary and tertiary effluents on receiving surface and ground waters and in possible reuse systems.

(8) The ultimate disposal of treated and untreated solids remains unsolved. The traditional approach has been to consider the land as a disposal "sink" for residual waste solids and liquids. There is considerable doubt that this can be sustained on a long term basis. While investigations will continue on the quantity and quality of liquids and solids that can be disposed of on the land, investigation of other ultimate disposal techniques, such as incineration, wet oxidation, and reuse deserve attention.

It is recommended that considerable emphasis be given to the assessment of feasible ultimate disposal techniques for untreated solids and liquids as well as for the residues from waste treatment processes. These techniques should be integrated with feasible handling and treatment processes to develop over-all waste control and abatement systems.

(9) The increase in the number of large scale animal production facilities and the number of animals per facility has resulted from the fact that income from animal production operations has either decreased

or stayed the same while the cost of living has increased. There is almost a complete lack of cost information relating to animal waste treatment processes and systems. It is imperative that all research studies collect and report information that can be used to estimate the cost of feasible systems. Field studies on as large a scale as possible are valuable not only to determine performance under actual environmental conditions but to obtain realistic data on the cost of such systems.

It is recommended that all animal waste research and developmental projects be oriented to obtain cost data to evaluate potential treatment and abatement systems. Economic studies should be conducted to evaluate: (a) the effect of the costs of waste control and abatement on the costs of animal production, (b) the effect of the costs of animal production on the costs of waste control and abatement, (c) the costs that will ultimately be borne by the consumer, and (d) the need for subsidies to insure adequate animal waste control and abatement.

(10) Recent accomplishments in controlling pollution from agricultural sources in England have occurred because of better regulatory control and continuing education and research. These achievements can be duplicated and exceeded in the United States. Wastes from animal production facilities should not be classified as "uncontrollable" or "natural."

It is recommended that large scale animal production facilities be considered as individual industries, and that they be considered subject to State and Federal regulations concerning pollution abatement. Current Federal and State regulations should be reviewed to ensure that they adequately cover pollution caused by animal production facilities.

(11) Developments in the control and abatement of animal wastes are in a state of flux. These wastes were not significant less than two decades ago. Because of the rapid increase in confinement feeding facilities, they have become a major source of pollution in certain parts of the country. Research, developmental, and educational efforts are only now getting underway. These efforts will be increased in the future.

It is recommended that a forward oriented review be conducted in five years to assess the developments in that time and to develop directions for the future.

FIGURE 12

RECOMMENDED ACTIVITIES FOR ANIMAL WASTE
CONTROL AND ABATEMENT

ANIMAL WASTES

DEVELOPMENTAL
RESEARCH

1) Economics of Waste Control
    - a) effect on the national economy
    - b) need for subsidy
    - c) effect on costs of animal production
    - d) interrelationships of animal waste management systems
2) Handling Processes and Systems
    - a) liquid and solid wastes
    - b) treated and untreated wastes
    - c) cost and management studies
3) Treatment Processes and Systems
    - a) liquid and solid wastes

FIELD RESEARCH
AND DEVELOPMENT

1) Land Disposal Studies
    - a) for total disposal
    - b) for crop response
    - c) potential ground and surface water pollution
    - d) seasonal, soil, crop variation
    - e) treated and untreated wastes
    - f) cost studies
2) Animal Management Studies
    - a) effect of waste management
    - b) changes in confinement feeding operatings and effect on waste management
    - c) effect of rations on waste production
    - d) source control

EDUCATION

1) Formal Education and Training
    - a) M.S. level
    - b) Ph.D. level
2) Senior Fellowships
    - a) for professionals in other disciplines
3) Workshops
    - a) dissemination of information
4) General Public
    - a) magnitude of the problem
    - b) cost of the problem
5) Agricultural Community
    - a) magnitude and cost of the problem
    - b) potential and feasible control and abatement systems

FIGURE 12--(Continued)

b) loadings, performance, effluent quality
c) aerobic, anaerobic, tertiary
d) cost studies

4) Effect of Effluents and Solid Residues on the Environment

a) surface and ground water effect
b) potential reuse

5) Ultimate Disposal

a) treated and untreated wastes
b) incineration
c) landfill
d) wet oxidation
e) reuse
f) land disposal
g) cost studies

6) Documentation of Pollutions

a) short range effect in streams
b) long range effects in reservoirs, lakes
c) data on all pollutional parameters

3) Effect on Environment

a) treated and untreated wastes
b) surface and ground water
c) odors, nuisances

4) Reuse

a) treated and untreated waste as animal feed
b) water reuse

5) Demonstration Projects

a) feasibility and cost evaluations of systems investigated in the developmental projects

6) Operating Personnel

a) education of those who will operate and maintain the feasible control and abatement systems

FIGURE 12--(Continued)

7) Waste Characteristics

   a) included in each project
   b) effect of animal management techniques
   c) effect of waste collection and handling

8) Development of Analytical Techniques

   a) for liquid wastes
   b) for solid wastes

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